POWER SYSTEM ANALYSIS AT PLANT DISTRIBUTION SYSTEM

By

NURUL FARHANA BINTI ABDUL RAHIM

Dissertation

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

(Dr. Ir. Idris Ismail)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(Nurul Farhana Binti Abdul Rahim)

ABSTRACT

This paper presents the analysis of power system and the approaches taken to model and simulate power system of an industrial plant. The analysis is very crucial in planning, designing, and operating stages of the system to confirm all the design parameter are as per system design requirement to avoid any interruption in supply which may cause a loss in revenue as well as jeopardising the safety of the plant and plant personnel. To predict and understand the behavior of this system, analysis including load flow study for steady-state operation and short circuit study to calculate the maximum fault current need to be done. The main objective of this project is to develop an analysis of a practical plant model which includes all the important elements in a power system. The scope of the project includes the modeling and simulation of the industrial plant using a computer-aided simulation tool. Correct input, output data and assumption shall be made to ensure all the simulation and data interpretations are accurate. The model plant here refers to an industrial petrochemical plant. MATLAB has been chosen to model and simulate the power system analysis due to its flexible software structure with wide selection of toolbox, model, and programme which enable user to perform engineering analysis in specific condition. In this simulation, the actual behavior of the system can be analyzed. Within a time frame of 12 months, the project is assumed feasible as it only uses established data from one of a petrochemical plant and development of the model in software for simulation. Finally all the calculation result will be observe and analyze to observe the behavior of the system. The simulation also allows the engineer to assess the performance of the system during the design stage and when system is already operating.

ACKNOWLEDGEMENT

All praises be to Allah S.W.T, The Most Gracious, The Most Merciful for His Guidance and Blessing. I would like to take this opportunity to thank the following parties for their help and support in ensuring the successfulness of this project. Firstly to my project supervisor, Ir. Dr. Idris Ismail for giving me all the valuable guidance, comments and suggestions which really help me to improve on many aspect of this project. Also thank you to Dr Nursyarizal Mohd Nor for his useful guidelines and encouragement in completing this project.

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I also wish to express my appreciation to fellow friends and my families for their constant support throughout the endeavor.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

The analysis of power system is central importance in the planning, design, and operating stages of power system as well as planning for its future expansion. It is very crucial to design a practical power system which should be safe, convenience and economical to provide continues power supply to the industrial plant. Without proper analysis, any interruption in supply may cause a loss in revenue as well as jeopardising the safety of the plant and plant personnel. Thus, the electrical engineers should understand all the aspect in electrical distribution system to ensure that it meets the plant requirements. In this project, the performances of the system has been analyzed using load flow study for steady-state operation and short circuit study to calculate the maximum fault current in response of disturbances. All the studies and modelling has been performed using the computer-aided simulation methods.

1.2 Problem Statement

"Power System Analysis at Plant Distribution System"
'Power System' is defined as the electric power system distribution network or system of a utility industrial plant. The model plant here refers to an industrial petrochemical plant. 'Analysis' here refers to study of the elements in power system to make sure all the design requirement is in the healthy condition. Further elaboration of the design requirement will be explained in the Section 1.2.2 Problem Identification. 'Plant Distribution System' is defined as systems of lines that connect the individual customer to the electric power system.

1.2.1 Problem Identification

In this project, all the analyses need to be performed to make sure all the equipments component and system design are as per system design requirement. This is to eliminate any system problem and to make sure all the following features are as good as possible:

1. Reliability to provide continues power supply to the industrial plant;
2. Safety to plant personnel and equipment during both operation and maintenance of the system;
3. Ease of maintenance and convenience of operation;
4. Electrical supply to equipment and machinery within the design operating limit;
5. Convenience load shedding during contingency operation to prevent total plant shutdown;
6. Adequate provision for future extension and modification without forcing extensive or total plant shutdown;

While performing the analysis, mathematical modeling requires knowledge and calculation of fault impedance values and other essential parameters. Thus, it is important that the plant equipment characteristic and the power system behavior are known. Correct assumption shall be made to ensure all the simulation and data interpretations are accurate. While performing the modeling, the author needs to understand the right method of modeling the system using Power System Toolbox (PST) and Power System Analysis Toolbox (PSAT) in MATLAB(R).

1.2.2 Project Significance

Power system analysis by modeling and simulation can predict the performance and behavior of system in real time operation of the plant. As the problem identification is to understand the power system problem which are interruption in supply, voltage sags and swells, waveform distortion, transient condition, voltage fluctuation and frequency deviation. Thus, this project will develop an effective methodology to eliminate the problem and to design effective requirement of the system, which led to highlight the project problem statement. In this project, the selected main analyses are load flow study to investigate the magnitude and phase angle of the voltage at each bus and the real and reactive power flows in the system component, and short circuit study to calculate the maximum fault current in the designated equipment, as well as understanding of all the elements in electrical distribution system. This project also serves as a baseline for modeling of more complex system. It can be used as an introduction for undergraduate students to learn and explore more knowledge on power system analysis and starting point for postgraduate or expended studies.

1.2 Objectives and Scope of Study

The main objective of this project is to perform an analysis of a practical plant model which includes all the important elements in a power system of an industrial plant. The elements here include the load flow study and short circuit study as well as modelling of electrical machines. The analysis will confirm the power system is as per design requirement. It also serves as a subject matter expert for understanding the elements of power system engineering. Apart from that, the other objective of this final year project is to be exposed in solving and completing a technical project in electrical engineering field.

The scope of the project includes the modelling and simulation of the industrial plant in a computer-aided simulation tool. In this simulation, the actual behavior of the system can be analyzed. The study will be based on the single line diagram and relevant data of an industrial petrochemical plant. The project is relevant to the analysis of basic power distribution in electrical engineering field. Thus the project can be used as a practical operational tool to check the performance of the system during real or contingency conditions. Within a time frame of 12 months, the project is assumed feasible as it only uses established data from one of a petrochemical plant and development of the model in software for simulation.

CHAPTER 2
LITERATURE REVIEW

2.1 Modeling of Electrical Machine

The representation of the elements by means of appropriate assumption and mathematical model is critical to the successful analysis of the electrical power systems. Rotating machines in the plant fault calculation may be analysed in four categories which are synchronous generator (in this case, gas turbine generator), synchronous motors and condenser, induction machines/load, and electrical utility system [Natarajan, 2002]. For fault calculations, each component of electrical machines is represented by a suitable impedance value. All the machines type, typical assumptions and references are summarize in the table below [Das, 2002];

Table 1: Typical Assumptions for Modeling of Electrical Machines

Machines/ Equipment	Typical Assumptions	References
Utility/TNB Supply	1. 132kV incomers connected to 11kV main switchboard via 2 132/11kV step down transformer. 2. Three phase fault current at 132kV TNB is given as 6.8kA per line. R/X = 0.125.	[1] [3] [6–8] [11]
Gas Turbine Generator	1. Modeled as 12500kVA 2. X_d" = 0.25 = Sub-transient reactance, during 1st cycle. 3. X_d' = 0.36 = Transient reactance, during 1 to 2 seconds. 4. X_d = 0.60 = Reactance, during steady state. 5. Ac component of the generator fault current: $\mathrm{Iac} = \left[\frac{1}{X''d} - \frac{1}{X'd}\right] e^{-\frac{t}{Td''}} + \left[\frac{1}{X'd} - \frac{1}{Xd}\right] e^{-\frac{t}{Td'}} + \frac{1}{Xd}$ (1)	[1] [3-4] [6-11]

	6. Dc component of the generator fault current: $$\text{Idc} = (\sqrt{2})\left(\frac{1}{Xd}\right)e^{-\frac{t}{Td}} \quad (2)$$ 7. Total generator fault current It: $$\text{It} = \sqrt{Iac^2 + Idc^2} \quad (3)$$	
Induction Motor	1. Fault current from an induction motor is due to generator action produced by load after the fault. The field flux is produced due to the stator voltage and hence the current contribution decays very rapidly upon the clearing as the terminal voltage is removed.	[1-3] [5-8] [11]
Transformer	1. 11/0.433kV for the plant are modelled based on rating 1000kVA with Z% impedance 6%. 2. It is off load tap changers of ±5.0% with 2.5% step. 3. The impedance values are given in percentage on the transformer kVa rating and are converted to per unit on the study base.	[1-3] [5-7] [9] [11]
Cables	1. The low voltage cables and group of LV motors have been combined to a single equivalent motor for simplification. Rated Current = 5 ; R/X =0.42. 2. The kVa rating is approximately equal to the house power rating. The sub-transient reactance is given by the locked rotor reactance.	[1] [3] [6-8] [11]
Switchgear and Motor Control Centre	1. The system nominal voltages are 132kV, 11kV, 3.3kV and 0.415kV. 2. In all scenarios (normal and contingency operation), the 11kV bus-section at the plant will be kept closed.	[1-3] [5-8] [11]

2.1.1 The Per-Unit Method

The solution of an interconnected power system having several different voltage levels requires the cumbersome transformation of all impedances to a single voltage level. In per-unit system, a balanced three-phase system, the relationship of three phase kVa, line to line voltage, base current and base impedance are defined as [Saadat, 2004]:

$$Per-unit\ quantity = \frac{actual\ quantity}{base\ quantity} \tag{4}$$

$$Base\ current,\ Ib\ (amperes) = \frac{base\ kVa\ (1000)}{\sqrt{3}base\ volts)} = \frac{Base\ kVa}{\sqrt{3}(Base\ kv)} \tag{5}$$

$$Base\ impedance,\ Zb\ = \frac{base\ volts\ (1000)}{\sqrt{3}(base\ impedance)} = \frac{(Base\ kVa)^2}{Base\ MVA} \tag{6}$$

$$Per-unit\ impedance, Xpu = \frac{actual\ impedance\ in\ ohms\ (base\ MVA)}{base\ kV^2} \tag{7}$$

$$= \frac{actual\ impedance\ in\ ohms\ (base\ kVA)}{base\ kV^2(1000)} \tag{8}$$

Transformer impedance are in the percent of transformer rating in kilovolts-amperes and converted using:

$$Xpu = \frac{percent\ impedance\ (base\ kVa)}{kVA\ rating\ (100)} \tag{9}$$

The motor reactance are converted using:

$$Xpu = \frac{per-unit\ reactance\ (base\ kVa)}{kVA\ rating} \tag{10}$$

2.2 Load Flow Study

Load flow study is a solution of the steady-state operation condition of a power system. The study will focus on collection of data, formulation line and bus admittance matrix and finally perform iterative techniques using Gauss-Seidel Method. This load flow study will confirm the busbar voltages are capable to operate within the ±5% voltage deviation of the rated voltage [PFKSB, 2008],[Das, 2002]. This is achieved through adjustment of generator vars, capacitor banks and off load tap changer of the transformer. It will also calculate the distribution power loss. In addition, load flow study is required for many other analyses such as transient stability and contingency study [Das, 2002][Saadat, 2004].

The system is assume to be operated under balance condition and is represented by a single phase network. In this study, power factor control is one of the important factors as the electrical equipment is rated on a KVA basis, and a lower power factor derates the equipment and limits its capacity to supply active power loads. The reactive power can be provided by the shunt capacitors, synchronous generators and other synchronous machines [Natarajan, 2002], [Saadat, 2004]. The important of power factor (reactive power) control can be broadly stated as improvement in the active power handling capability of transmission lines, improvement in voltage stability limits, increasing capability of existing system – the improvement in power factor for release of a certain per unit kVA capacity, reduction of losses [Das, 2002].

With Power Factor improvement, the current per unit for the same active power delivery is reduced. It will also contribute to the improvement of the transmission line regulation; the power factor improvement improves the line regulation by reducing the voltage drop on load flow [Idris and Shashiteran, 2002]. In this particular plant model, the overall system power factor, inclusive of reactive power losses in transformer and other distribution system equipment, shall not be less than 0.8 lagging at rated design throughout of the plant. When the power is supplied from a public utility, the plant power system shall be design so that the power factor stated by the public utility us achieved with a design margin of at least 2%[PFKSB, 2008], [P.T.S. 33.64.10.10].

In load flow calculation, a transformer can act as a control element. Voltage control is achieved by adjusting of taps on the windings, which change the turn ratio. The taps can be adjusted under load, providing automatic control of the voltage. The under load taps generally provided ±10%-20% voltage adjustments around the rated transformer voltage, in 16 or 32 steps. Off-load taps provide ±5% voltage adjustment. Transformer can also provide phase-shift control to improve the stability limits. The reactive power flow is related to voltage change and voltage adjustments indirectly provide reactive power control [Das, 2002], [Saadat, 2004].

The mathematical formulation of the power flow problems usually involved a system of non-linear algebraic equations which require the use of iterative techniques namely Gauss-Siedel and Newton-Rapson Methods. Network data and bus power data are supplied as input data. Bus voltages are calculated for the given network configuration and bus power injection. For this project, iterative method using Newton-Rapson Method which is been chosen. [Mercede, 1999].

2.2.1 Non-Linear Algebraic – Newton-Raphson Method

The Newton Raphson Method is mathematically superior with the number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required at each iteration [Saadat, 2004]. To illustrate the technique, consider the solution of the nonlinear equation given by:

$$f(x) = c \qquad (11)$$

The $x^{(0)}$ is an initial estimate of the solution and $\Delta\, x^{(0)}$ is a small deviation from the correct solution,

$$f\left(x^{(0)} + \Delta x^{(0)}\right) = c \qquad (12)$$

Expanding the left-hand side of the above equation in Taylor's series about $x^{(0)}$,

$$f\left(x^{(0)} + \left(\frac{df}{dx}\right)^{(0)}\Delta x^{(0)} + \frac{1}{2!}\left(\frac{d^2f}{dx^2}\right)^{(0)}\left(\Delta x^{(0)}\right)^2\right) = \cdots c \qquad (13)$$

Successive use of this procedure yields the Newton-Raphson algorithm

$$\Delta c^{(k)} = c - f\left(x^{(k)}\right) \qquad (14)$$

Where $\Delta c^{(k)} = \left(\frac{df}{dx}\right)^{(k)}\Delta x^{(k)}$, shows that the nonlinear equation (11) is approximated by the tangent line on the curve at $x^{(k)}$. A linear equation is obtained in terms of the small changes in variable. The intersection of the tangent line with x-axis results in $x^{(k+1)}$ [Saadat, 2004], [Das, 2002].

2.3 Short Circuit Study

A short circuit study or fault calculation is performed to calculate the maximum fault current that would be present in the system during system disturbance. It is also known as fault analysis. Whenever a fault occurs, the bus voltages and flow of current in the network elements get affected. These fault may occurs due to insulation failure in the equipments, due to flashover of lines initiated by lightning stroke, due to mechanical damage to conductors and towers and due to accidental faulty operation. There are two types of faults, which are symmetrical (three phase bolted for zero impedance) fault and unsymmetrical (single line-to-ground, line-to-line and double line-to-ground) fault [Mercede, 1999].

When a short circuit occurs, a new circuit is established with lower impedance, and increases the current. In the case of a bolted short circuit the impedance is drastically reduced, and the current is increases to a very high value in a fraction of a cycle. It is assume that in the short circuit study, all the shunt parameters like loads are neglected, all the transformer taps are at the nominal position, and prior to fault, all the generators are assumed to operate at rated voltage of 1.0 p.u. with their emf's in phase [Natarajan, 2002]. The study was simulated to determine the bolted three-phase fault at the switchboards. This fault will be used to confirm the short circuit rating of the switchboard [PFKSB, 2008], [IEC 60909-0, 2001].

2.3.1 *Three Phase Symmetrical Fault*

The three-phase fault is calculated using: $\mathrm{I} = \frac{\mathrm{E}}{\mathrm{Z}}$ relationship, where E is bus voltage matrix, I is the bus nodal current matrix and Z is the R + jX in complex form. The three-phase fault here is referring to the bolted fault which mean the fault is having zero fault impedance [Idris and Shashiteran, 2002], [Saadat, 2004]. The symmetrical rms fault current (1/2 to 1 cycle) is:

$$I_{sc} = \frac{kVA_b}{\sqrt{3} \times kV_b \times X_{pu}} \tag{15}$$

2.3.2 *Unsymmetrical Faults*

Unsymmetrical faults occur as single line to ground, line to line and double line to ground faults. The order of the phasors is a,b,c. For the original current phases, they are been designed as Ia, Ib, and Ic. A multiplication factor of 1.6 must be applied to account for the effect of the direct-current component of initial (first-cycle) fault current [Natarajan, 2002].

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

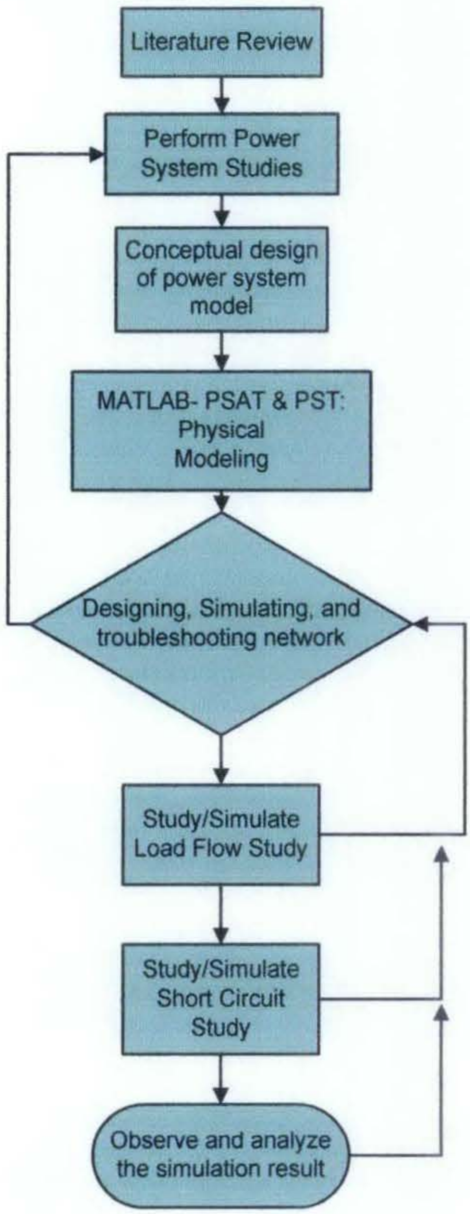


Figure 1: Project Work Flow

The project involves two main objectives, which to analyse the power system model and simulate the model in computer aided tools. In order to fulfill this objective, proper project planning has been done. Besides that, the time limitation should be taken into consideration. Figure 1 shows the Project Work Flow and Appendix 1 shows the Project Gantt Chart for author planning.

From Figure 1, the project work flow is started with the theories gathered from the literature research, the methodology of the project was determined. After learning the MATLAB using Power System Toolbox (PST) and Power System Analysis Toolbox (PSAT), the project activities continue with designing, simulating, analysis and troubleshooting the elements in power system which are load flow study and short circuit study. Finally, the author will observe and analyze the simulation result and compare it with the theories gained in the literature review.

3.2 Modeling and simulation system using MATLAB

MATLAB has been chosen to model and simulate the power system analysis due to its flexible software structure with wide selection of toolbox, model, and program which enable user to perform engineering analysis in specific condition. In solving the load flow study, the system is assumed to be operated under balanced conditions and a single phase is used. The results from this analysis are including voltage magnitudes and degrees, loads, line flows and losses.

3.2.1 Power System Toolbox (PST)

The Power System Toolbox, containing a set of M-files, used with permission from Hadi Saadat to assist some typical power system analysis. These programs have been refined and modularized for interactive used with MATLAB. The software modules are structured in such way that the user may mix them for other analysis. The programs used for load flow study are *ybus, lfbus, ifgauss, ifnewton, decouple, busout* and *lineflow* while for the fault analysis are *dlgfault, lgfault, llfault, symfault,* and *Zbus.* From the single line diagram, busbar a and busbar b which connected with closed bus section are assumed to be one busbar. Function of each programs are as per table 2 and table 3 below [Saadat, 2004]:

Table 2: List of program for load flow study

Load Flow Study	
ybus1	Obtains $Y_{bus,}$ given R and X values
lfybus	Obtains $Y_{bus,}$ given Π model with specified linedata field
ifnewton	Power flow solution by the Newton-Raphson method
busout	Returns the bus output result in tabular form
lineflow	Returns the line flow and losses in tabular form

Table 3: List of program for fault analysis

Symfault(Z1,Zbus1,V)	Line to ground fault
Zbus=zbuildpi(linedata, gendata, load)	Builds the impedance matrix, compatible with load flow data

3.2.2 Power System Analysis Toolbox (PSAT)

Power System Analysis Toolbox, (PSAT), used with the permission from Federico Milano is used in this project [Milano, 2005]. PSAT is aimed to perform power flow, optimal power flow, continuation power flow and electromechanical transients, for static and dynamic analysis and control of electric power systems. PSAT includes power flow, continuation power flow, optimal power flow, small signal stability analysis and time domain simulation. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides a user friendly tool for network design.

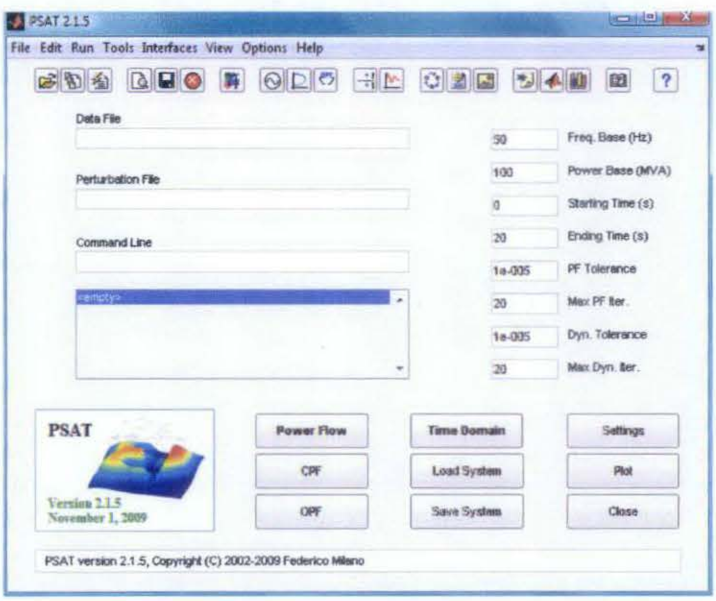


Figure 2: Power System Analysis Toolbox, (PSAT)

CHAPTER 4

3.3 Detailed Procedure for Fault Calculation

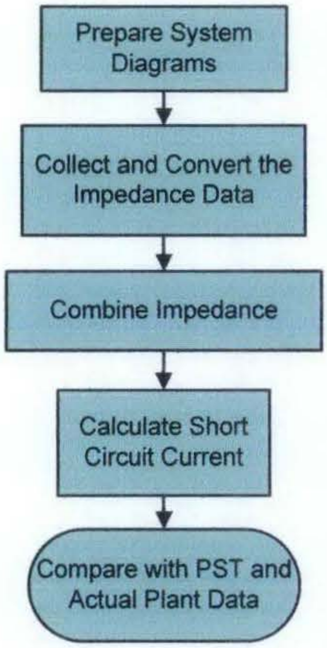


Figure 3: Detailed Procedure for Fault Calculation

The significant part of preparing the system diagram is to establish the impedance diagram of the selected system. All the impedance data of each component will be converted to per unit system. After combining all the impedance for simplification, the next step is to calculate the short circuit current. A multiplication factor of 1.6 must be applied to account for the effect of the direct-current component of initial fault current. The result will later be compared with the computational result from PST and actual plant data.

RESULT AND DISCUSSION

4.1 Modeling the system

The single line diagram of the plant is simplified as the figure below. In this petrochemical plant, power supply from TNB is stepped down from 132kV to 11kV via two 132/11kV transformers and feeds to 11kV intake switchboard. Only one out of two 11kV circuit breakers (1 out of 2) is closed for TNB supply to maintain parallel electrical connection to Cogeneration (COGEN) Plant at all times.

Simplified One-Line diagram of Cogeneration Plant

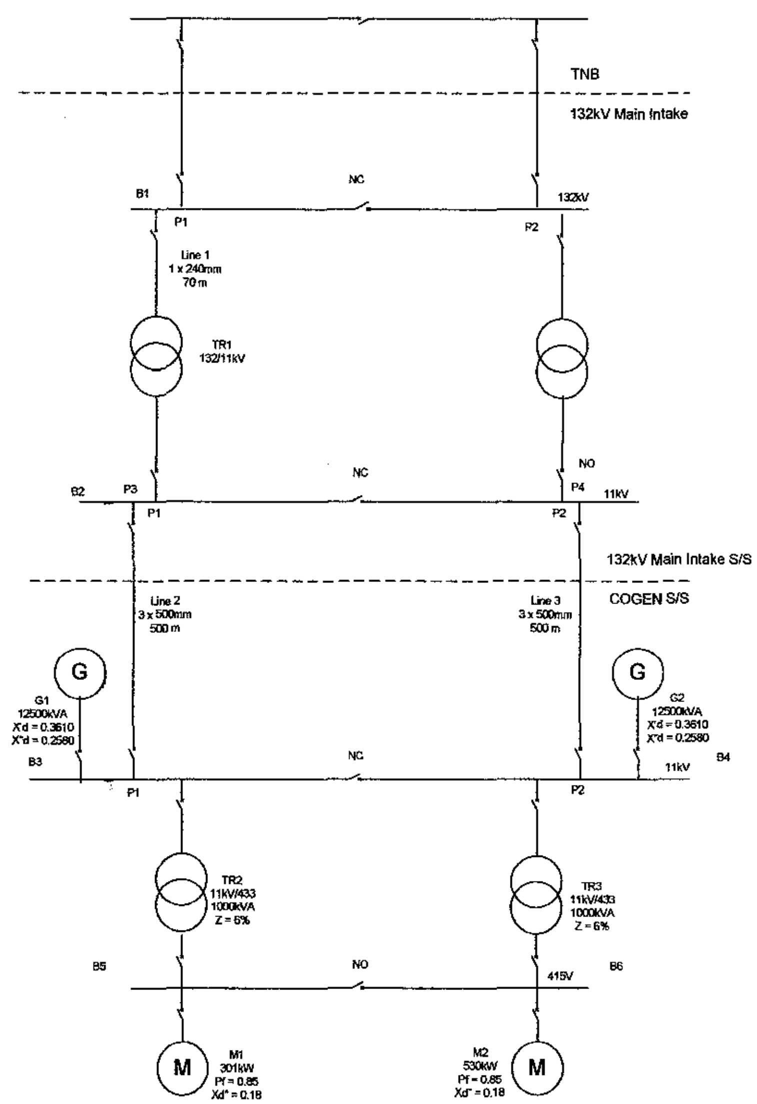


Figure 4: Simplified One Line Diagram of Co-generation Plant

The Co-generation plant is connected with the main intake substation to distribute the supply to the petrochemical plant. For this project, the Co-generation plant is modelled connected to the Urea plant. The data for each device is given as the table below. The data for the injected Q due to shunt capacitors at B2 is 1.6 Mvar. The simplified one line diagram of the Urea plant is given as the figure below [PFKSB, 1996], [PFKSB, 2008]:

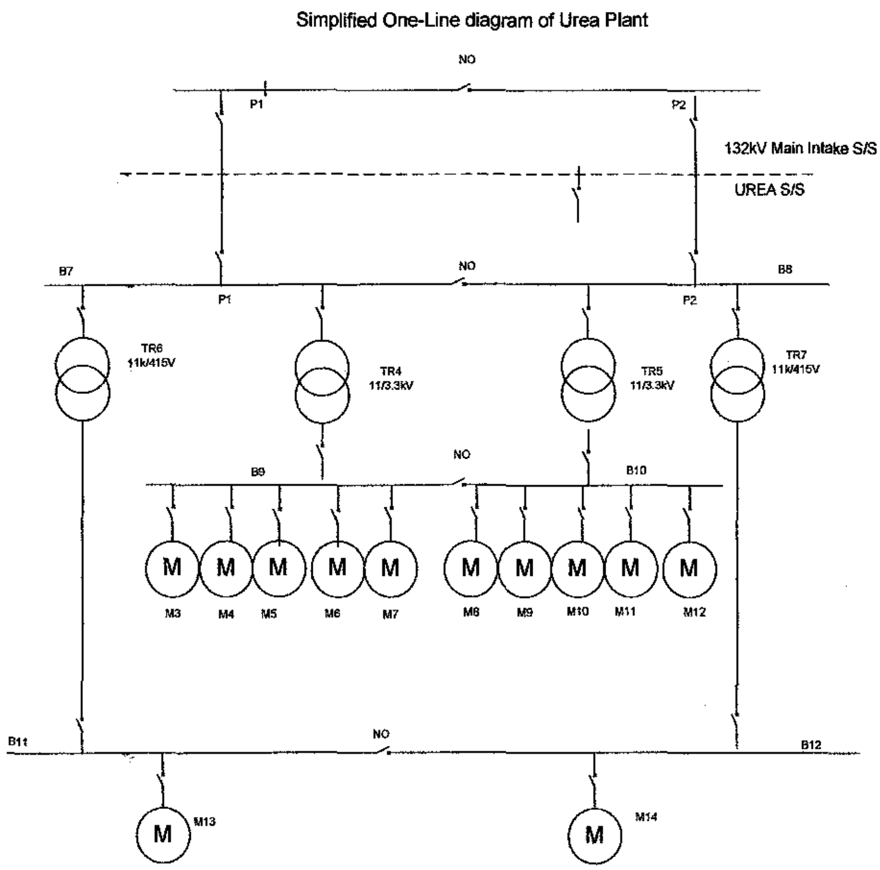


Figure 5: Simplified One Line Diagram of Urea Plant

Table 4: Specification and Rating of each component in the system:

Electrical Equipment	**Real Power, Power Factor and Apparent Power Rating**	**Voltage Rating**	**Per-Unit Reactance**
TNB incomer	500kW PF 0.9 320 750kVA	132kV	
T1	20MVA	132/11kV	X = 10.5%
G1 = G2	12.5MVA	11kV	$X'_d = 0.3610$
T2 = T3	1MVA	11k/433V	X = 6%
M1	301kW PF 0.85 204.450kVA	415V	$X''_d = 0.18$
M2	530kW PF 0.85 360kVA	415V	$X''_d = 0.18$
T4 = T5	8MVA	11k/3.3kV	X = 9.5%
T6 = T7	1.6MVA	11k/415V	X = 5.8%
M3= M8	1330kW PF 0.91 843.8kVA	3.3kV	$X''_d = 0.17$
M4=M9	600kW PF 0.91 380.67kVA	3.3kV	$X''_d = 0.17$
M5	1250kW PF 0.87 829.53kVA	3.3kV	$X''_d = 0.17$
M6	200kW PF 0.81 142.56kVA	3.3kV	$X''_d = 0.17$
M7	430kW PF 0.77 322.4kVA	3.3kV	$X''_d = 0.17$
M10	960kW PF 0.88 629.84kVA	3.3kV	$X''_d = 0.17$
M11	810kW PF 0.84 556.73kVA	3.3kV	$X''_d = 0.17$
M12	230kW PF 0.85 156.224kVA	3.3kV	$X''_d = 0.17$
M13=M14	512kW PF 0.89 332.139kVA	415V	$X''_d = 0.17$

4.1 Converting Impedance to Per Unit Values

The base power will be chosen as 100 MVA. The data for the injected Q due to shunt capacitor is 3.2MVA at bus 2.

Calculation on base impedance:

At 11kV, if resistance is neglected,

$$X_b = \frac{11^2}{100} = 1.21\Omega$$

At 3.3kV, if resistance is neglected,

$$X_b = \frac{3.3^2}{100} = 0.1089\,\Omega$$

At 415V, if resistance is neglected,

$$X_b = \frac{0.415^2}{100} = 0.0017\,\Omega$$

The multipliers will be used in this study to simplify the conversion of the impedance to Per Unit Values.

Utility Supply Equivalent Reactance

$$X_{pu} = \frac{1.0 \times 100M}{555\ 556k} = 0.18\ pu$$

132/11kV 20MVA Transformers

$$X_{pu} = \frac{0.105 \times 100}{20} = 0.525\ pu$$

Line 1, 70m 1 x 240mm (noted that one 1mm = 39.4mil) and (1m = 3.28),

Referring to Appendix 5, Xa = 0.0769/1000ft, Xd = 0.0571/1000ft. Total reactance is

$$X_{tot} = X_a + X_d = \frac{0.0198\ \times 70m \times 3.28ft}{1000ft\ \times 1m} = 4.5461m\Omega$$

$$X_{pu} = \frac{4.5461m}{1.21} = 3.76m\ pu$$

Line 2 and 3, 500m 3 x 500mm (noted that one 1mm = 39.4mil) and

(1m = 3.28), Referring to Appendix X, Xa = 0.123/1000ft, Xd = -0.0571/1000ft. Total reactance:

$$X_{tot} = X_a + X_d = \frac{0.0659 \times 500m \times 3.28ft}{1000ft \times 1m} = 0.1081\Omega$$

$$X_{pu} = \frac{0.1081}{1.21} = 0.0893\,pu$$

Line 4 and 5, 770m 3 x 500mm (noted that one 1mm = 39.4mil) and (1m = 3.28), Referring to Appendix X, Xa = 0.113/1000ft, Xd = -0.0571/1000ft. Total reactance is

$$X_{tot} = X_a + X_d = \frac{0.0559 \times 770m \times 3.28ft}{1000ft \times 1m} = 0.1412\Omega$$

$$X_{pu} = \frac{0.1081}{1.21} = 0.1167\,pu$$

11kv/415V 1MVA Transformers

$$X_{pu} = \frac{0.06 \times 100}{1} = 6\,pu$$

11kv/415V 1.6MVA Transformers

$$X_{pu} = \frac{0.058 \times 100}{1.6} = 3.63\,pu$$

11kv/3.3kV 8MVA Transformers

$$X_{pu} = \frac{0.095 \times 100}{8} = 1.19pu$$

12.5MVA Gas Turbine Generator. From the generator datasheet, effective sub-transient reactance Xd"=23.1%.

$$X_{pu} = \frac{0.231 \times 100}{12.5} = 1.848\,pu$$

204.450kVA, 0.85 p.f. lagging load at B4.

$$X_{pu} = \frac{0.18 \times 100M}{204.450k} = 88.04\,pu$$

360kVA, 0.85 p.f. lagging load at B5.

$$X_{pu} = \frac{0.18 \times 100M}{360k} = 50\,pu$$

843.8kVA, 0.91 p.f. lagging load at B9 and B10.

$$X_{pu} = \frac{0.17 \times 100M}{843.8k} = 20\,pu$$

380.67kVA, 0.91 p.f. lagging load at B9 and B10.

$$X_{pu} = \frac{0.17 \times 100M}{380.67k} = 44.66\,pu$$

829.53kVA, 0.87 p.f. lagging load at B9.

$$X_{pu} = \frac{0.17 \times 100M}{829.53k} = 20.5\,pu$$

142.56kVA, 0.81 p.f. lagging load at B9.

$$X_{pu} = \frac{0.17 \times 100M}{142.56k} = 119.2\,pu$$

322.4kVA, 0.77 p.f. lagging load at B9.

$$X_{pu} = \frac{0.17 \times 100M}{322.4k} = 52.73\,pu$$

629.84kVA, 0.88 p.f. lagging load at B10.

$$X_{pu} = \frac{0.17 \times 100M}{629.84k} = 27\,pu$$

556.73kVA, 0.87 p.f. lagging load at B10.

$$X_{pu} = \frac{0.17 \times 100M}{556.73k} = 30.5\,pu$$

156.224kVA, 0.84 p.f. lagging load at B10.

$$X_{pu} = \frac{0.17 \times 100M}{156.224k} = 108.82\,pu$$

332.139kVA, 0.89 p.f. lagging load at B11 and B12.

$$X_{pu} = \frac{0.17 \times 100M}{332.139k} = 51.2\,pu$$

4.3 Load Flow Study

Load Flow study using Newton Rapson Method in MATLAB using several programs which is **lfgauss**, which is preceded by **lfybus**, and is followed by **busout** and **lineflow** [Das, 2002]. Generation and loads in the given data prepared is defined as **busdata.** Code 0, 1, and 2 are used for load buses, slack buses and voltage controlled busses. Values for basemva, accuracy, accel, and maxiter are specified as: basemva = 100; accuracy = 0.001; accel = 1.8; maxiter = 100;

lfybus – The program requires the line and transformer parameters and transformer tap settings specified in the input file named **linedata.** It converts impedances to admittances and obtains the bus admittance matrix. The program is designed to handle parallel lines.

Lineflow – This program prepares the line output data. It is designed to display the active and reactive power flow entering the line terminals and line losses as well as the net power at each bus.

lfgauss – The program obtains the power flow solution by Newton Rapson Method and requires the files named busdata and linedata. It is designed for the direct use of load and generation in MW and Mvar, bus voltage in per unit, and angle in degrees. The programs will produce the following result:

Power Flow Solution by Newton-Raphson Method

Maximum Power Mismatch = 7.07146e-006
No. of Iterations = 3

Bus No.	Voltage Mag.	Angle Degree	Load MW	Load Mvar	Generation MW	Generation Mvar	Injected Mvar
1	1.060	0.000	0.000	0.000	-8.415	10.245	0.000
2	1.010	2.365	0.000	0.000	0.000	0.000	3.200
3	1.010	2.383	0.000	0.000	18.000	-5.894	0.000
4	0.998	1.356	0.301	0.204	0.000	0.000	0.000
5	1.000	0.579	0.530	0.360	0.000	0.202	0.000
6	1.007	2.145	0.000	0.000	0.000	0.000	0.000
7	0.976	-0.492	3.800	2.500	0.000	0.000	0.000
8	0.975	-0.585	3.930	2.560	0.000	0.000	0.000
9	0.995	1.082	0.512	0.332	0.000	0.000	0.000
10	0.995	1.082	0.512	0.332	0.000	0.000	0.000
Total			**9.585**	**6.288**	**9.585**	**4.553**	**3.200**

Line Flow and Losses

Line from	Line to	Power at bus & line flow MW	Mvar	MVA	Line loss MW	Line loss Mvar	Transformer tap
1		-8.415	10.245	13.258			
	2	-8.415	10.245	13.258	0.000	0.821	
2		0.000	3.200	3.200			
	1	8.415	-9.424	12.634	0.000	0.821	
	3	-17.169	6.288	18.284	0.000	0.006	
	6	8.754	6.336	10.807	-0.000	0.051	
3		18.000	-5.894	18.941			
	2	17.169	-6.281	18.282	0.000	0.006	
	4	0.301	0.212	0.368	0.000	0.008	
	5	0.530	0.177	0.559	-0.000	0.018	
4		-0.301	-0.204	0.364			
	3	-0.301	-0.204	0.364	0.000	0.008	
5		-0.530	-0.158	0.553			
	3	-0.530	-0.158	0.553	-0.000	0.018	
6		0.000	0.000	0.000			
	2	-8.754	-6.285	10.777	-0.000	0.051	
	7	3.800	2.759	4.696	-0.000	0.259	
	8	3.930	2.835	4.846	0.000	0.275	
	9	0.512	0.346	0.618	0.000	0.014	
	10	0.512	0.346	0.618	0.000	0.014	
7		-3.800	-2.500	4.549			
	6	-3.800	-2.500	4.549	-0.000	0.259	
8		-3.930	-2.560	4.690			
	6	-3.930	-2.560	4.690	0.000	0.275	
9		-0.512	-0.332	0.610			
	6	-0.512	-0.332	0.610	0.000	0.014	
10		-0.512	-0.332	0.610			
	6	-0.512	-0.332	0.610	0.000	0.014	
Total loss					**-0.000**	**1.466**	

Figure 7: Simulation Result for Load Flow studies

From the simulation result we can see the injected capacitor bank , 3.2Mvar at bus 2, generation of 18 MW at bus 3, as well all the voltage magnitude, angle degree, and load at each busses. All the computation result will then compare with the result from modeling the system in PSAT and the data from the industrial petrochemical plant. The result for line flow for the line from bus 2 to bus 8 and from bus 2 to bus 3 are as below:

Table 5: Power Flow from Bus 2 to Bus 8

	kW	kvar	kVA
Actual Plant Data	3836.2	2189.6	4417.1
PSB	8754	6336	10807
PSAT	6740	n/a	18170

Table 6: Power Flow from Bus 2 to Bus 3

	kW	kvar	kVA
Actual Plant Data	7123.5	3237.5	7824.7
PSB	17.169M	6281	18282
PSAT	3494	n/a	7581

From the analyze result, for table 5, we can see the result from PST and PSAT is slightly higher than the actual plant data. For table 6, the result is much higher than the actual plant data. This may be due to the actual plant data is calculated overall input value from all the petrochemical complex while the PSAT and PST is just using the main intake substation, co-generation plant and urea plant.

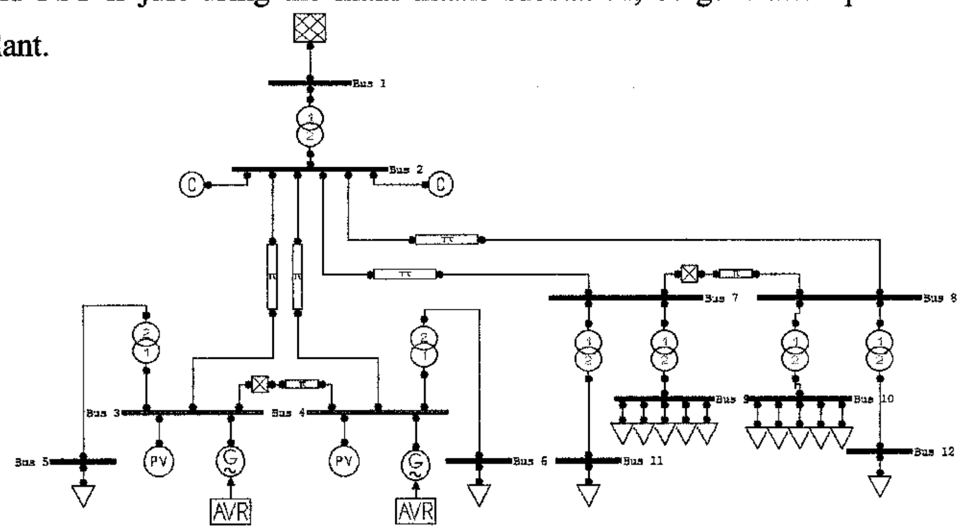
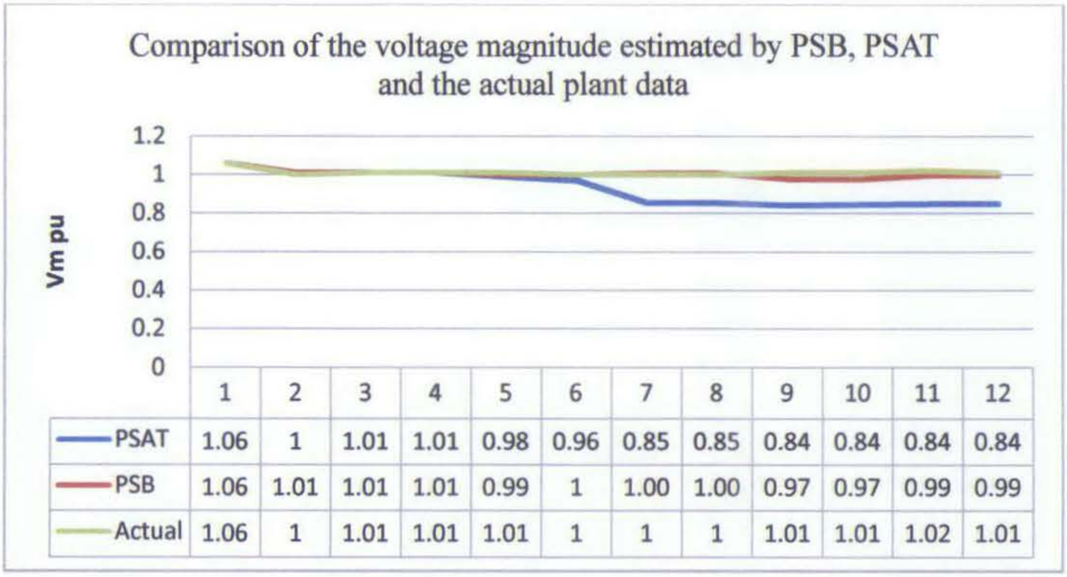


Figure 8: Single Line Diagram Simulate in PSAT



	1	2	3	4	5	6	7	8	9	10	11	12
PSAT	1.06	1	1.01	1.01	0.98	0.96	0.85	0.85	0.84	0.84	0.84	0.84
PSB	1.06	1.01	1.01	1.01	0.99	1	1.00	1.00	0.97	0.97	0.99	0.99
Actual	1.06	1	1.01	1.01	1.01	1	1	1	1.01	1.01	1.02	1.01

Figure 9: Comparison Of The Voltage Magnitude Estimated By PSB, PSAT And The Actual Plant Data in Per Unit value.

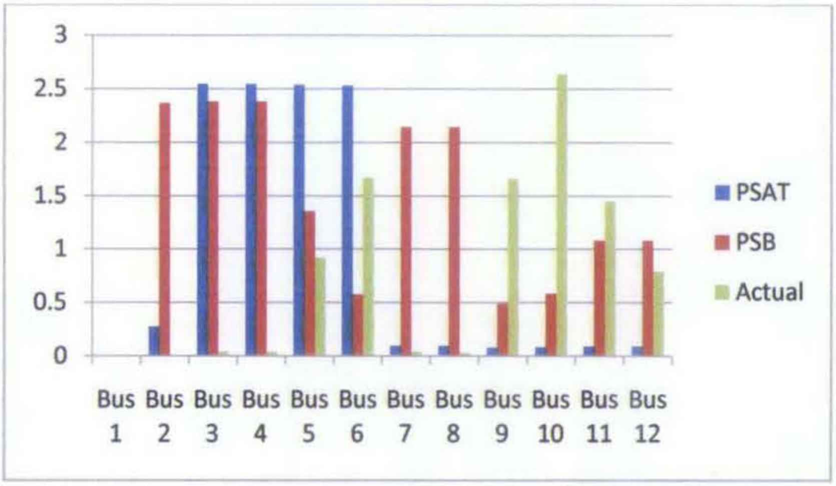


Figure 10: Comparison Of The Angle Degree Estimated By PSB, PSAT And The Actual Plant Data in Per Unit value.

The voltage magnitude for the actual data from the petrochemical plant, the PSAT simulation and PST is illustrated in the figure 9. It is clear that all the busbar are within the acceptable limit ±5% of the rated voltage. This 5% refers to the PTS 33.64.10.10. During normal operating system operation and under steady state conditions, the voltage at the generator and customer terminals shall not deviate from the rated equipment voltage by more than 5% [P.T.S 33.64.10.10, 2002].

4.4 Short Circuit Study

Using the calculated per-unit reactance, the author performed an impedance diagram and calculated manually the fault current at Bus 2 and Bus 3. This diagram should be as simplified as possible, retaining the points at which fault current is to be calculated.

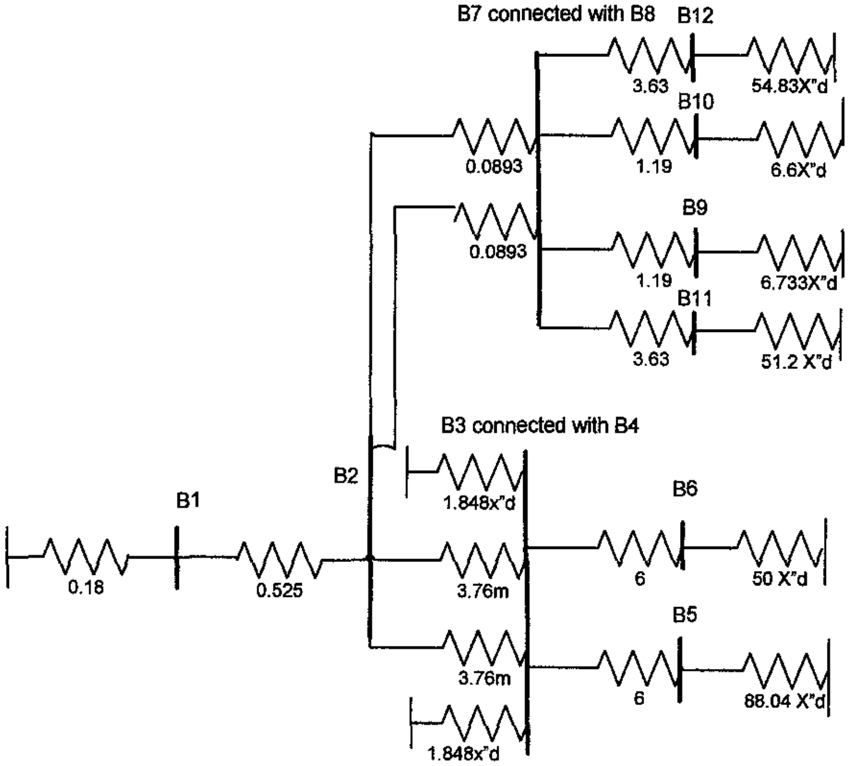
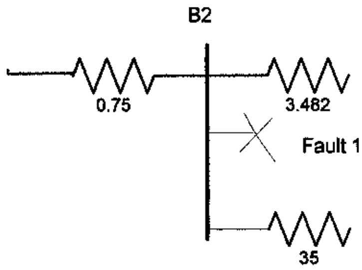


Figure 11: Impedance Diagram Constructed from Single Line Diagram

Further simplification of the reactance diagram will be made for two specific fault locations, which are at the Bus 2 (11kV Busbar, Main Intake Substation – Distribution Substation) and Bus 3 (11kV Busbar, Co-Generation Plant Substation). Consider the base apparent power is 100MVA.

For fault 1, the simplification of the reactance diagram into a single equivalent reactance is shown in figure below:



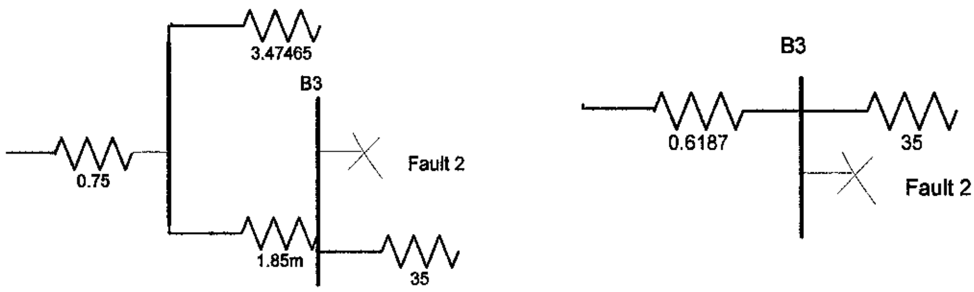
$\frac{1}{x} = \frac{1}{0.705} + \frac{1}{3.17}$, Thus x = 0.6065

$$I_{sc} = \frac{100M}{\sqrt{3} \times 11k \times 0.6065} = 8.65kA$$

Figure 12: Impedance Calculation for Fault 1

The asymmetrical fault current at location 2 is $I_{sc} = 1.6 \times 8.65kA = 13.846$

For fault 2, the simplification of the reactance diagram into a single equivalent reactance is shown in figure below:



(a) (b)

Figure 13: Impedance Calculation for Fault 2

$\frac{1}{x} = \frac{1}{0.6167} + \frac{1}{35}$, Thus x = 0.6060 $I_{sc} = \frac{100M}{\sqrt{3} \times 11k \times 0.606} = 8660.8A$

The asymmetrical fault current at location 2 is $I_{sc} = 1.6 \times 8.66kA = 13.857$

Comparing result for fault 1 and fault 2 with the short circuit rating, both calculated fault current are still within the short circuit rating.

Next, the author performed symmetrical fault analysis **(symfault)** and unsymmetrical fault analysis **(lgfault, llfault, dlgfault).** The program **symfault** is designed for the balanced three-phase fault analysis of a power system network. The program requires the bus impedance matrix Zbus, obtained by the inversion of Ybus or it may be determined either from the function Zbus = zbuild(zdata) or the function Zbus = zbuildpi(linedata, gendata, yload). The program prompts the user to enter the faulted bus number and the fault impedance Zf. The prefault bus voltages are defined by the reserved Vector V. The array V may be defined or it is returned from the power flow programs lfgauss, lfnewton, decouple or perturb. If V does not exist the prefault bus voltages are automatically set to 1.0 per unit. The program obtains the total fault current, the postfault bus voltages and line currents [Saadat, 2004].

This is to check the maximum fault current that would be present in the system disturbance is calculated to confirm the adequacy of switchgear related to short circuit withstand rating (kVa). The comparison of the three-phase short circuit result between the estimated fault current, actual estimated fault current and the short circuit rating at each busbar is illustrated as below:

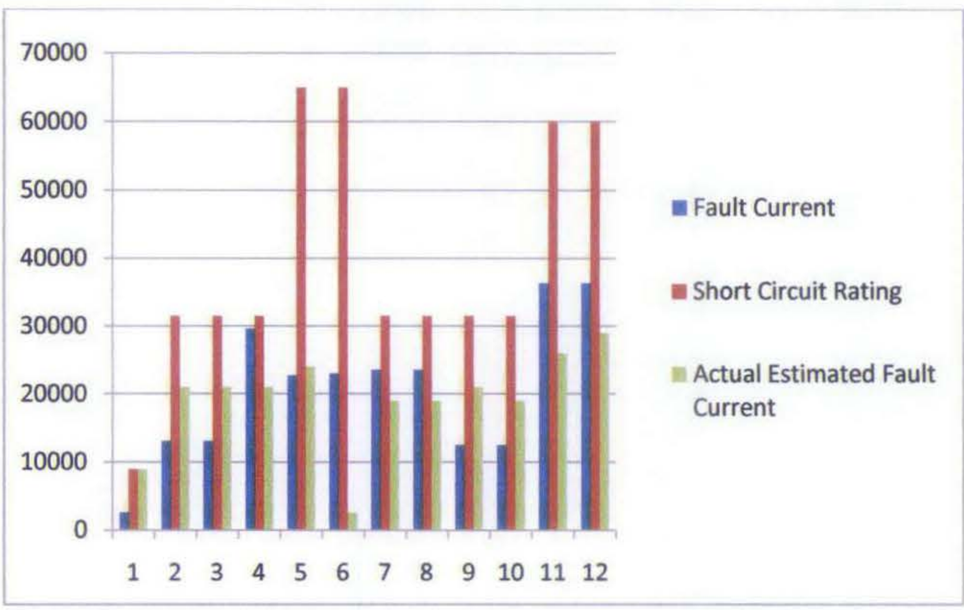


Figure 14: The Comparison Of The Three-Phase Short Circuit Result Between The Estimated Fault Current, Actual Estimated Fault Current And The Short Circuit Rating At Each Busbar.

Table 7: Three Phase Short Circuit Result:

Busbar Location	Fault Current	Actual Estimated Fault Current	Short Circuit Rating
1	2624	8948.6	10000
2	13121	21000.4	31500
3	13121	21000.0	31500
4	29648	21000.0	31500
5	22746	24000.7	65000
6	23024	26000.6	65000
7	23584	19000.2	31500
8	23584	19000.1	31500
9	12528	21000.8	31500
10	12528	19000.5	31500
11	36394	26000.8	60000
12	36394	29000.2	60000

Referring to PTS 33.64.10.10 Electrical Engineering Guidelines, for the new switchboard at inteke, power plant, or distribution substations, a margin of not less than +10% shall be allowed between the calculated fault level under the above mentioned conditions and the specified short circuit rating of the equipment. Therefore, in the view of PTS requirement, it is clear that all the short circuit rating are within the proposed switchboard ratings except for bus 4. The value of fault current calculated in matlab for bus 4 is exceed the requirement 10%. Again this may be due to the limited input data compare to overall petrochemical plant data used for the actual estimated fault data.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Performing the analysis of power system is essential in determine the power system behavior. Through gathering all the data, perform required calculation, development of mathematical model of elements in power system, simulation of the system in MATLAB and finally analysis of the results, the author will able to appreciate the characteristic and behavior of the power system. The accuracy of the result will critically depend on the input and output data as well as the plant model design. From the project, it is conclude that the analysis is crucial in the design of power system. The simulation also allows the engineer to assess the performance of the system during the design stage and when system is already operating.

The essential requirements for load flow study are for high speed system, convergence characteristics, which are of major consideration for large systems, and the capability to handle ill-conditioned systems, ease of modification and simplicity for adding, deleting and changing system components, generator outputs, loads, and bus types, and consideration for storage requirement, which becomes of consideration for large systems. Throughout the study, the student is able to understand and appreciate the utility system parameters as voltage magnitude, line loading and line losses, and how the contingency operations affect the overall system.

From the model and calculations, we can see the simplification is quite simple once all the data rating is collected and all the impedance is converted in per-unit values. The impedance diagram can then be use to model each elements in the power system. From here we can calculate the fault current manually and compare the result with the simulation result. From symmetrical rms fault current, a multiplication of 1.6 must be applied to account for the effect of the direct-current component to calculate the asymmetrical fault current.

Thus, throughout this project, performing the analysis of a practical plant model is relevant to understand the power system elements. The elements here include the load flow study and short circuit study as well as modeling of electrical machines. In performing the modeling and simulation of the industrial plant in a computer-aided simulation tool, correct input, output data and assumption shall be made to ensure all the simulation and data interpretations are accurate.

5.2 Recommendation

While completing this project, it is important that the program and the methods used in the simulation part to be fully understood for easier modification so that the required performance can be obtained. Thus, with proper understanding of the interaction of the model in the PST and PSAT, the components model can be access and modified accordingly. It is also recommended to develop a Graphical User Interface (GUI) which can be a user friendly and simple interface for users with basic or no background in MATLAB or programming language. This GUI also can be used to help them to perform the simulation according to their preference on the power system model. The analysis also will be understand more accurately if the author able to perform her own program to calculate the power flow and short circuit analysis using other's programming software like C++.

5.3 Future Work Plan

Finally, suggested future work for project expansion and continuation is to perform the transient stability analysis study to check the stability of a system during and after sudden changes or disturbances in the system. Power system stability is an electromechanical phenomenon and is defined as the ability of designed synchronous machines in the system to remain in synchronism with one another following disturbance such as fault and fault removal at various locations in the system [Kundur and Morison, 1997].

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APPENDICES

APPENDIX I – Gantt Chart for First Semester and Second Semester

APPENDIX 1 – Gantt Chart for First Semester

Name: Nurul Farhana Abdul Rahim – 8399 **Supervisor: Dr. Ir. Idris Ismail**

Project Title: Power System Analysis at Plant Distribution System

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Selection of Project Topic																	
2	First Meeting with FYP Supervisor																	
3	Preliminary Research Work																	
4	Study and Research Literature Review for: 1. Purpose to perform the FYP 2. Load Flow Study 3. Short Circuit Study																	
5	Submission of Preliminary Report																	
6	Seminar 1 (optional)																	
7	Submission of Progress Report																	
8	Seminar 2 (compulsory)																	
9	Done several case studies																	
10	Submission of Interim Report Final (Draft)																	
11	Submission of Interim Report Final																	
12	Oral Presentation																	

APPENDIX 1 – Gantt Chart for Second Semester

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Project Continuation																	
2	Continue the modelling for: 1. Load Flow Study 2. Short Circuit Study 3. Perform Contingency Analysis																	
3	Submission of Progress Report 1																	
4	Submission of Progress Report 2																	
5	Project Exhibition																	
6	Submission of Dissertation Final Draft																	
7	Submission of Dissertation Final																	
8	Submission of Technical Report																	
9	Oral Presentation																	
10	Submission of Dissertation Final (Hardcopy)																	

APPENDIX II – Single Line Diagram and Power System Description

APPENDIX 2 – Single Line Diagram and Power System Description

DESCRIPTION OF PETROCHEMICAL PLANT ELECTRICAL SUPPLY SYSTEM

In this petrochemical plant, power supply from TNB is stepped down from 132kV to 11kV via two 132/11kV transformers and feeds to 11kV intake switchboard. Only one out of two 11kV circuit breakers (1 out of 2) is closed for TNB supply to maintain parallel electrical connection to Cogeneration (COGEN) Plant at all times. The normal electrical configuration adopted at the 11kV intake switchboard shall be:

a. One out of two 11kV Incomers circuit breakers closed for supply.
b. Both 11kV generation feeders' circuit-breakers closed for supply.
c. Bus tie at 11kV intake switchboard closed.
d. All 11kV outgoing plant feeder circuit-breakers closed.

The petrochemical plant power demand from TNB is controlled and maintained at 500kW through this single parallel connection with COGEN Plant. In the event of scheduled outage for maintenance or failure of one GTG, power demand may increase momentarily or for short durations to fully sustain PFK plant operations without disruption. Export to TNB is not permitted under normal operation. Reverse power can be experienced during "load rejection" condition (such as during stopping a big motor) while running in parallel with TNB. An alarm shall be generated by Electrical Network Monitoring Control System (ENMCS) in case such power exceeds a predetermined value.

The COGEN substation supply its own utilities through two 11/0.433kV unit transformers tagged TR3 and TR4 to 415V switchboard at B7 and B8. This COGEN Utility switchboard is connected to the existing 415V Emergency Diesel-powered Generators (EDG) system to provide blackstart capability.

Description of Cogeneration Plant

The Cogeneration Plant (COGEN) comprises of generation from two gas turbine generators (GTGs), each rating 10MVA, tagged as G1 and G2 connected to a 11kV generator switchboard tagged as B1. The simplified one line diagram for the plant is as below:

Simplified One-Line diagram of Cogeneration Plant

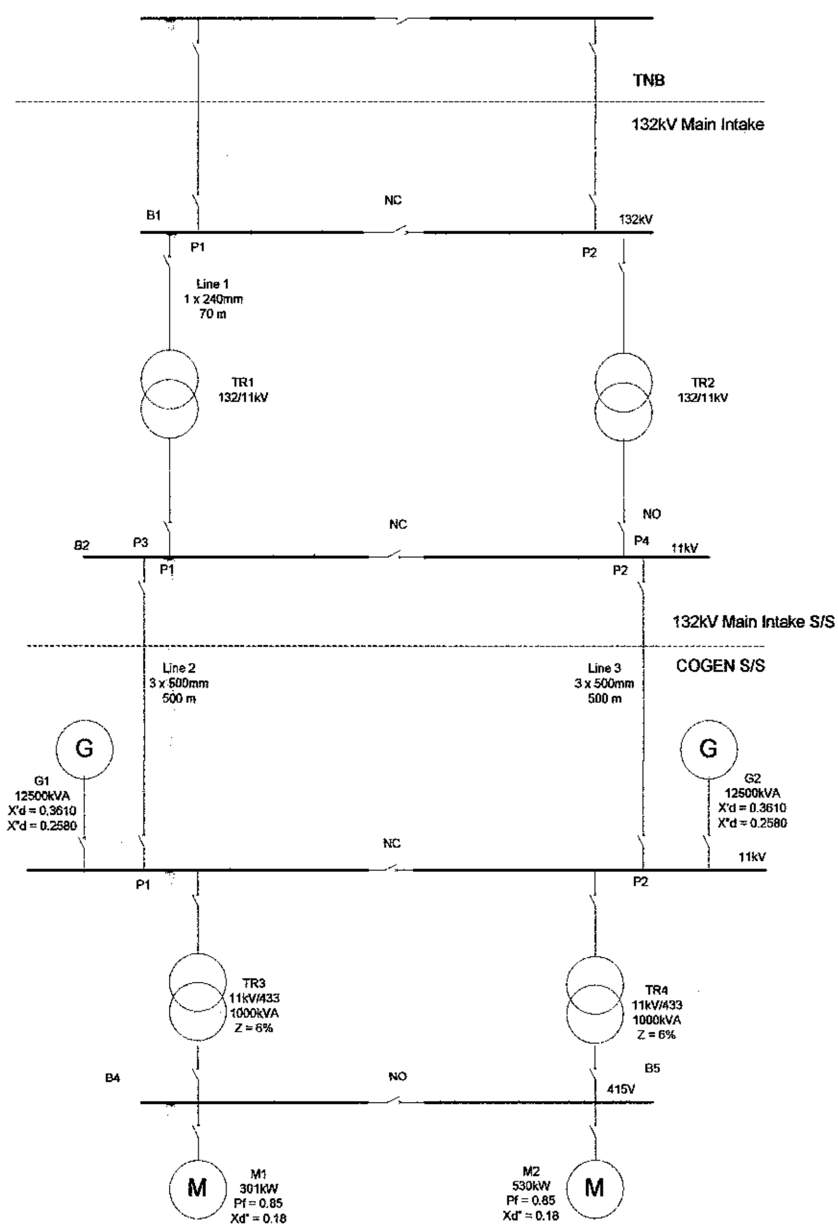
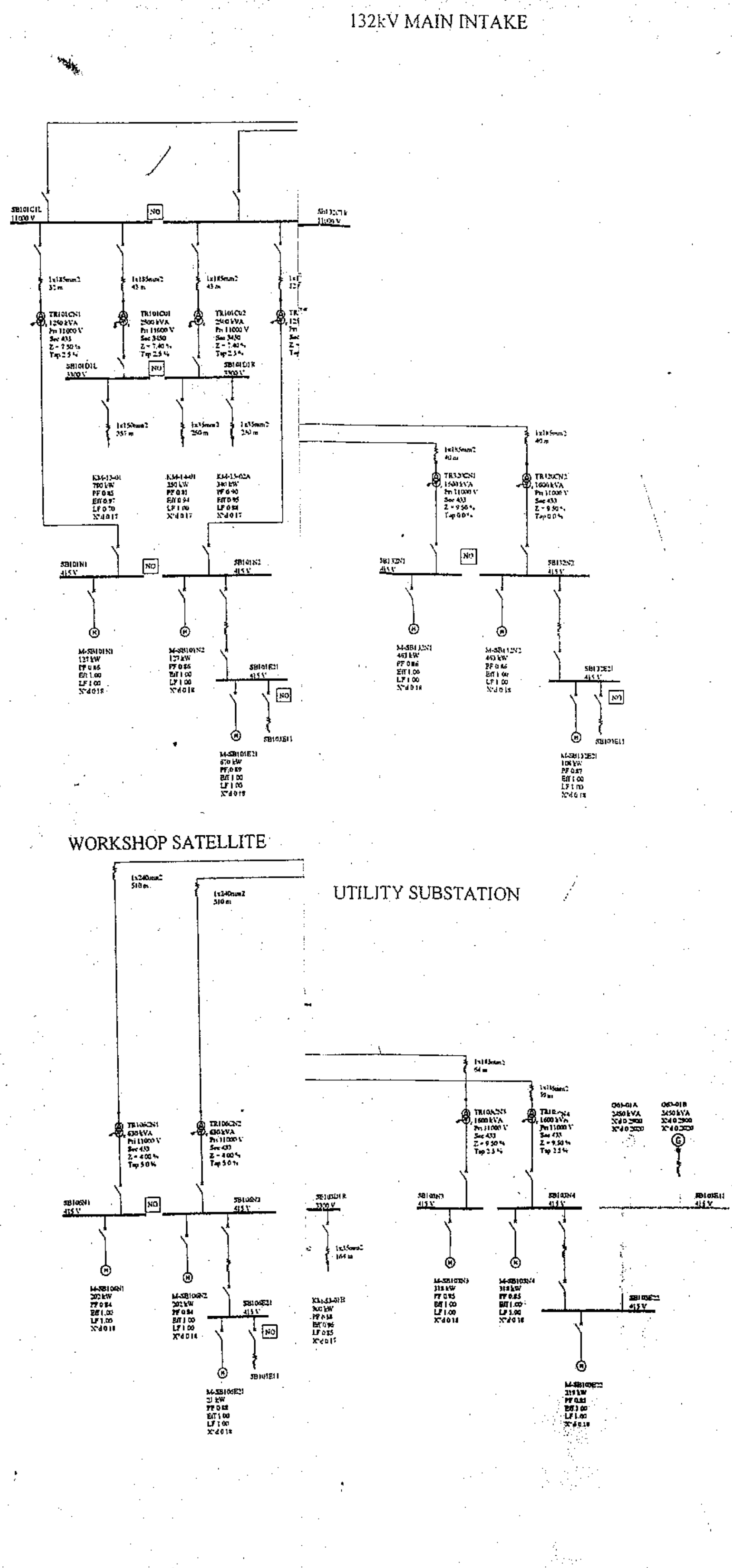


Figure 4: Simplified One Line Diagram of Co-generation Plant

In normal operation, the cogeneration system will be connected in parallel with TNB. TNB will be top up either 500kW or 1000kW and standby power to provide for all the petrochemical plant power requirement. The import power will be controlled by Electrical Network Monitoring and Control System (ENMCS). During engineering stage, there is another future gas turbine generator to be designed for incorporation into cogeneration system.

The purposes of this Cogeneration Plant are:

a. To reduce operating cost by generating power in-house and generating steam using waste heat from the GTGs.
b. To provide reliable generation and distribution of power to the petrochemical plant.
c. To meet the total plant normal demand of 13MWe with minimum power import from TNB under normal operating conditions.
d. To be capable of operating in "Island Mode" by choice during normal plant operation whilst maintaining the capability to spontaneously power import from TNB during planned maintenance and/or contingency conditions.


132kV MAIN INTAKE
WORKSHOP SATELLITE
UTILITY SUBSTATION

APPENDIX III – Actual Plant Three Phase Short Circuit Result and Load Flow Result

Three Phase Short Circuit Results

No	Busbar/Switchgear	Location	Rated Voltage (kV)	Short circuit rating	Three Phase Short Circuit Results (Ik")						
					Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
1	SB132C1L	132kV Main Substation	11	31.5kA - 1s	21.40	30.60	21.50	16.00	24.20	**33.40**	0.00
2	SB132C1R	132kV Main Substation	11	31.5kA - 1s	21.40	30.60	21.50	16.00	24.20	**33.40**	0.00
3	SB101C1L	Ammonia & Urea Substation	11	31.5kA - 1s	17.00	22.30	19.10	13.50	18.70	23.70	0.00
4	SB101C1R	Ammonia & Urea Substation	11	31.5kA - 1s	17.10	22.30	19.10	13.50	18.70	23.70	0.00
5	SB102C1L	Ammonia & Urea Substation	11	31.5kA - 1s	19.20	26.10	20.50	14.60	21.30	28.00	0.00
6	SB102C1R	Ammonia & Urea Substation	11	31.5kA - 1s	19.10	26.00	20.50	14.60	21.20	27.90	0.00
7	SB103C1L	Utilities Substation	11	31.5kA - 1s	17.70	23.40	19.60	13.70	19.50	24.90	0.00
8	SB103C1R	Utilities Substation	11	31.5kA - 1s	17.60	23.20	19.60	13.70	19.30	24.70	0.00
9	SB104C1L	Urea Handling Substation	11	31.5kA - 1s	15.90	20.30	18.40	12.70	17.30	21.40	0.00
10	SB104C1R	Urea Handling Substation	11	31.5kA - 1s	15.90	20.30	18.40	12.70	17.30	21.40	0.00
11	SB201C1L	Cogen Substation	11	31.5kA - 1s	21.10	29.90	21.20	15.90	23.90	**32.70**	0.00
12	SB201C1R	Cogen Substation	11	31.5kA - 1s	21.10	29.90	21.20	15.90	23.90	**32.70**	0.00
13	SB101D1L	Ammonia & Urea Substation	3.3	31.5kA - 1s	5.30	5.50	9.90	5.20	5.40	5.50	0.00
14	SB101D1R	Ammonia & Urea Substation	3.3	31.5kA - 1s	5.30	5.50	9.90	5.20	5.40	5.50	0.00
15	SB102D1L	Ammonia & Urea Substation	3.3	31.5kA - 1s	21.80	23.30	**33.70**	15.50	22.40	23.70	0.00
16	SB102D1R	Ammonia & Urea Substation	3.3	31.5kA - 1s	19.50	21.00	**33.70**	15.50	20.00	21.30	0.00
17	SB103D1L	Utilities Substation	3.3	31.5kA - 1s	17.80	19.00	27.50	14.20	18.30	19.30	0.00
18	SB103D1R	Utilities Substation	3.3	31.5kA - 1s	15.70	16.90	27.50	14.20	16.10	17.10	0.00
19	SB101N1	Ammonia & Urea Substation	0.415	60kA - 1s	23.10	23.40	49.70	21.80	23.30	23.50	0.00
20	SB101N2	Ammonia & Urea Substation	0.415	60kA - 1s	28.40	28.70	49.70	21.80	28.50	28.80	0.00
21	SB102N1	Ammonia & Urea Substation	0.415	60kA - 1s	26.80	27.10	54.00	22.30	26.90	27.20	0.00
22	SB102N2	Ammonia & Urea Substation	0.415	60kA - 1s	29.20	29.50	54.00	22.30	29.30	29.60	0.00
23	SB103N1	Utilities Substation	0.415	60kA - 1s	24.80	25.10	52.10	22.20	24.90	25.10	0.00
24	SB103N2	Utilities Substation	0.415	60kA - 1s	29.30	29.60	52.10	22.20	29.50	29.70	0.00
25	SB103N3	Utilities Substation	0.415	60kA - 1s	25.20	25.60	50.40	22.20	25.40	25.60	0.00
26	SB103N4	Utilities Substation	0.415	60kA - 1s	27.10	27.40	50.40	22.20	27.20	27.40	0.00
27	SB104N1	Urea Handling Substation	0.415	60kA - 1s	26.50	26.80	51.10	22.10	26.60	26.90	0.00
28	SB104N2	Urea Handling Substation	0.415	60kA - 1s	26.50	26.80	51.10	22.10	26.60	26.90	0.00
29	SB104N3	Urea Handling Substation	0.415	60kA - 1s	24.80	25.10	48.00	22.10	24.90	25.10	0.00
30	SB104N4	Urea Handling Substation	0.415	60kA - 1s	25.20	25.50	48.00	22.10	25.30	25.60	0.00
31	SB106N1	Workshop Satellite	0.415	60kA - 1s	22.40	22.60	43.20	20.40	22.50	22.70	0.00
32	SB106N2	Workshop Satellite	0.415	60kA - 1s	22.50	22.80	43.20	20.40	22.60	22.80	0.00
33	SB132N1	132kV Main Substation	0.415	60kA - 1s	26.60	27.00	52.10	22.50	26.80	27.00	0.00
34	SB132N2	132kV Main Substation	0.415	60kA - 1s	27.50	27.90	52.10	22.50	27.60	27.90	0.00
35	SB201E21L	Cogen Substation	0.415	65kA - 1s	24.70	25.00	49.30	21.90	24.80	25.10	0.00
36	SB201E21R	Cogen Substation	0.415	65kA - 1s	26.60	26.90	49.30	21.80	26.70	26.90	14.40
37	SB101E21	Ammonia & Urea Substation	0.415	60kA - 1s	26.90	27.20	44.30	20.40	27.00	27.30	21.50

Date: 5 March 2009
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Load Flow Summary Report

Load Flow Study Settings

Include Source Impedance	Yes	**Load Acceleration Factor**	0.10
Solution Method	Exact (Iterative)	**Bus Voltage Drop %**	5.00
Load Specification	1st Level Demand or Energy Factor	**Branch Voltage Drop %**	3.00
Generation Acceleration Factor	0.10		

Swing Generators

Source	In/Out Service	Vpu	Angle	kW	kvar	VD%	Utility Impedance
G63-01A	In	1.09	0.00	0.0	0.0	100.00	0.00 +j 0.00
G63-01B	In	1.09	0.00	0.0	0.0	100.00	0.00 +j 0.00
TNB	In	1.00	0.00	23.0	-5.3	-0.50	0.01 +j 0.06

PQ Generators

Participation PQ Source	In/Out Service	VD %	Vp.u.	KW	KVAR
G-59-01A	In	-0.80	1.010	7,550.0	3,530.0
G-59-01B	In	-0.80	1.010	7,550.0	3,530.0
G-59-01C	In	100.00	0.000	0.0	0.0

Bus Name	In/Out Service	Design Volts	LF Volts	Angle Degree	PU Volts	%VD
BUS-0066	In	3.300	3.339	-0.78	1.01	-1.20
BUS-0067	In	3.300	3.347	-0.79	1.01	-1.41
BUS-0068	In	3.300	3.376	-0.08	1.02	-2.30
BUS-0069	In	11.000	11.032	-0.04	1.00	-0.29
BUS-0070	In	11.000	11.055	-0.01	1.00	-0.50
BUS-0071	In	11.000	11.055	-0.01	1.00	-0.50
BUS-0072	In	3.300	3.376	-0.08	1.02	-2.30
BUS-0073	In	3.300	3.362	-0.01	1.02	-1.89
BUS-0074	In	11.000	11.043	-0.02	1.00	-0.39
BUS-0075	In	11.000	11.042	-0.02	1.00	-0.39
BUS-0076	In	11.000	11.043	-0.02	1.00	-0.39
BUS-0077	In	11.000	11.042	-0.02	1.00	-0.38
BUS-0078	In	3.300	3.376	-0.08	1.02	-2.30
BUS-0079	In	11.000	11.032	-0.04	1.00	-0.29
BUS-0080	In	11.000	11.032	-0.04	1.00	-0.29
BUS-0081	In	11.000	11.040	-0.02	1.00	-0.36
BUS-0082	In	11.000	11.039	-0.03	1.00	-0.36
BUS-0083	In	3.300	3.340	-0.83	1.01	-1.21
BUS-0084	In	3.300	3.340	-0.83	1.01	-1.21
BUS-0085	In	3.300	3.314	-0.68	1.00	-0.41
BUS-0086	In	3.300	3.333	-0.79	1.01	-0.99
BUS-0087	In	3.300	3.321	-0.76	1.01	-0.63
BUS-0088	In	11.000	11.031	-0.04	1.00	-0.28
BUS-0089	In	11.000	11.040	-0.02	1.00	-0.36
BUS-0090	In	3.300	3.340	-0.83	1.01	-1.21
BUS-0098	In	415	0	0.00	0.00	100.00

Bus Name	In/Out Service	Design Volts	LF Volts	Angle Degree	PU Volts	%VD
SB103N2	In	415	417	-2.56	1.01	-0.58
SB103N3	In	415	417	-1.07	1.01	-0.52
SB103N4	In	415	413	-1.78	0,99	0.54
SB104C1L	In	11.000	11.043	-0.02	1.00	-0.39
SB104C1R	In	11.000	11.043	-0.02	1.00	-0.39
SB104E21	In	415	417	-1.09	1.01	-0.57
SB104N1	In	415	414	-1.56	1.00	0.35
SB104N2	In	415	414	-1.56	1.00	0.35
SB104N3	In	415	418	-0.91	1.01	-0.83
SB104N4	In	415	417	-1.08	1.01	-0.59
SB106E21	In	415	409	-0.78	0.99	1.45
SB106N1	In	415	409	-0.70	0.99	1.33
SB106N2	In	415	409	-0.78	0.99	1.44
SB132A1L	In	132.000	132.660	0.00	1.01	-0.50
SB132A1R	In	132.000	132.660	0.00	1.01	-0.50
SB132C1L	In	11.000	11.055	-0.01	1.01	-0.50
SB132C1R	In	11.000	11.055	-0.01	1.01	-0.50
SB132E21	In	415	424	-1.81	1.02	-2.12
SB132N1	In	415	426	-1.44	1.03	-2.68
SB132N2	In	415	424	-1.79	1.02	-2.16
SB201C1L	In	11.000	11.065	0.04	1.01	-0.60
SB201C1R	In	11.000	11.065	0.04	1.01	-0.60
SB201E21L	In	415	419	-0.92	1.01	-0.86
SB201E21R	In	415	413	-1.67	1.00	0.38
SB201E31R0	In	415	413	-1.67	1.00	0.37

From Bus To Bus	Component Name	In/Out Service	%VD	kW Loss	kvar Loss	kVA Loss	LF Amps Rating %	PF
SB102C1L BUS-0056	CBL-0029	In	0.00	515.7 0.0	283.3 0.0	588.3 0.0	30.8 6.4	0.88
SB102C1R BUS-0055	CBL-0028	In	0.02	1,820.2 0.3	1,108.1 0.2	2,131.0 0.3	111.4 23.2	0.85
SB102C1R BUS-0057	CBL-0030	In	0.00	826.1 0.0	472.8 0.0	951.8 0.0	49.8 10.4	0.87
SB102D1L BUS-0058	CBL-0031	In	0.28	193.3 0.7	137.0 0.1	237.0 0.7	41.2 21.7	0.82
SB102D1L BUS-0059	CBL-0032	In	0.20	280.8 0.7	232.3 0.3	364.4 0.8	63.3 19.2	0.77
SB102D1L BUS-0060	CBL-0033	In	0.20	493.6 1.0	224.7 0.4	542.3 1.1	94.2 28.6	0.91
SB102D1L BUS-0061	CBL-0034	In	0.40	1,173.3 5.1	663.8 2.0	1,348.1 5.5	234.3 35.5	0.87
SB102D1L BUS-0062	CBL-0035	In	0.18	1,165.4 1.9	531.1 1.2	1,280.7 2.3	222.6 26.5	0.91
SB102D1R BUS-0063	CBL-0036	In	0.24	757.6 2.0	488.8 0.8	901.6 2.2	155.6 23.6	0.84
SB102D1R BUS-0064	CBL-0037	In	0.21	165.5 0.4	102.3 0.1	194.6 0.4	33.6 17.7	0.85
SB102D1R BUS-0065	CBL-0038	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB102D1R BUS-0066	CBL-0039	In	0.22	894.6 2.0	482.5 0.8	1,016.4 2.2	175.3 26.6	0.88

From Bus To Bus	Component Name	In/Out Service	%VD	kW Loss	kvar Loss	kVA Loss	LF Amps Rating %	PF
SB103D1L BUS-0085	CBL-0065	In	0.80	254.4 2.4	139.8 0.4	290.3 2.4	50.2 26.4	0.88
SB103D1L BUS-0086	CBL-0066	In	0.22	348.6 0.9	197.1 0.2	400.5 0.9	69.2 36.4	0.87
SB103D1L BUS-0087	CBL-0067	In	0.59	1,132.9 7.5	758.9 2.9	1,363.5 8.1	235.7 35.7	0.83
SB103D1L BUS-0090	CBL-0068	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103D1R BUS-0068	CBL-0056	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103D1R BUS-0072	CBL-0058	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103D1R BUS-0073	CBL-0059	In	0.41	128.0 0.6	70.6 0.1	146.2 0.6	25.0 13.2	0.88
SB103D1R BUS-0078	CBL-0060	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103E11 SB103E22	CBL-0014	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103E11 SB201E31R0	CBL-0012	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103E21 SB103E11	CBL-0074	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103N2 SB103E21	CBL-0057	In	0.13	544.7 0.4	352.5 0.9	648.9 1.0	897.5 52.7	0.84

From Bus To Bus	Component Name	In/Out Service	%VD	kW Loss	kvar Loss	kVA Loss	LF Amps Rating %	PF
SB132C1L BUS-0071	CBL-0044	In	0.00	465.8 0.0	292.8 0.0	550.2 0.0	28.7 6.0	0.85
SB132C1L SB101C1L	CBL-0003	In	0.01	127.2 0.0	76.7 0.0	148.5 0.0	7.8 1.4	0.86
SB132C1L SB102C1L	CBL-0005	In	0.20	3,836.2 6.2	2,189.6 6.5	4,417.1 9.0	230.7 20.8	0.87
SB132C1L SB103C1L	CBL-0007	In	0.21	2,322.2 4.1	1,508.2 4.3	2,769.0 6.0	144.6 26.1	0.84
SB132C1L SB104C1L	CBL-0009	In	0.11	756.2 0.7	518.6 0.7	917.0 1.0	47.9 8.6	0.82
SB132C1R BUS-0045	CBL-0018	In	0.02	223.8 0.0	146.4 0.0	267.5 0.0	14.0 2.5	0.84
SB132C1R BUS-0070	CBL-0043	In	0.00	575.7 0.0	363.8 0.0	681.0 0.0	35.6 7.4	0.85
SB132C1R SB101C1R	CBL-0004	In	0.08	807.2 0.5	474.1 0.6	936.1 0.8	48.9 8.8	0.86
SB132C1R SB102C1R	CBL-0006	In	0.14	2,649.4 3.0	1,584.1 3.2	3,086.8 4.4	161.2 14.5	0.86
SB132C1R SB103C1R	CBL-0008	In	0.14	1,483.0 1.7	1,001.5 1.8	1,789.5 2.5	93.5 16.8	0.83
SB132C1R SB104C1R	CBL-0010	In	0.11	807.9 0.8	548.9 0.8	976.7 1.1	51.0 9.2	0.83
SB132E21 SB103E11	CBL-0073	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00

From Bus To Bus	Component Name	In/Out Service	%VD	kW Loss	kvar Loss	kVA Loss	LF Amps Rating %	PF
SB106N2				1.0	4.9	5.0	42.2	
BUS-0046 SB101D1L	TR101C01	In	-2.01	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
BUS-0047 SB101D1R	TR101C02	In	-2.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
BUS-0048 SB101N1	TR101CN1	In	-1.19	127.2 0.2	76.7 1.4	148.5 1.4	8.0 9.5	0.86
BUS-0049 SB101N2	TR101CN2	In	1.91	806.6 8.8	473.6 54.0	935.4 54.7	49.0 59.6	0.86
BUS-0054 SB102D1L	TR102C01	In	-0.39	3,313.6 7.3	1,899.2 110.2	3,819.3 110.5	200.0 38.1	0.87
BUS-0055 SB102D1R	TR102C02	In	-1.06	1,820.0 2.3	1,107.9 34.3	2,130.7 34.3	111.0 21.2	0.85
BUS-0056 SB102N1	TR102CN1	In	-2.19	515.6 3.0	283.3 20.2	588.3 20.4	31.0 29.3	0.88
BUS-0057 SB102N2	TR102CN2	In	-0.82	826.1 7.9	472.8 52.8	951.8 53.4	50.0 47.4	0.87
BUS-0070 SB132N2	TR320CN2	In	-1.67	575.7 4.0	363.8 27.0	681.0 27.3	36.0 33.9	0.85
BUS-0071 SB132N1	TR320CN1	In	-2.18	465.7 2.6	292.8 17.6	550.1 17.8	29.0 27.4	0.85
BUS-0074 SB104N3	TR104CN3	In	-0.44	277.8 1.0	178.2 6.7	330.0 6.7	17.0 16.4	0.84
BUS-0075 SB104N4	TR104CN4	In	-0.21	329.4 1.4	208.4 9.3	389.8 9.4	20.0 19.4	0.85

From Bus To Bus	Component Name	%VD	kW Loss	kvar Loss	kVA Loss	LF Amps Rating %	PF
SB132A1L SB132A1R	PI-0001	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB132C1L SB132C1R	PI-0002	0.00	-567.9 0.0	-303.1 0.0	643.7 0.0	33.6 0.0	0.88
SB201C1L SB201C1R	PI-0003	0.00	113.7 0.0	79.3 0.0	138.6 0.0	7.2 0.0	0.82
SB201E21L SB201E21R	PI-0004	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB101C1L SB101C1R	PI-0005	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB101N1 SB101N2	PI-0006	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB101D1L SB101D1R	PI-0007	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB102C1L SB102C1R	PI-0008	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB102N1 SB102N2	PI-0009	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB102D1L SB102D1R	PI-0010	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103C1L SB103C1R	PI-0011	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103N3 SB103N4	PI-0012	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103D1L SB103D1R	PI-0013	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00

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Load Flow Summary Report

Load Flow Study Settings

Include Source Impedance	Yes	**Load Acceleration Factor**	0.10
Solution Method	Exact (Iterative)	**Bus Voltage Drop %**	5.00
Load Specification	1st Level Demand or Energy Factor	**Branch Voltage Drop %**	3.00
Generation Acceleration Factor	0.10		

Swing Generators

Source	In/Out Service	Vpu	Angle	kW	kvar	VD%	Utility Impedance
G63-01A	In	1.09	0.00	0.0	0.0	100.00	0.00 +j 0.00
G63-01B	In	1.09	0.00	0.0	0.0	100.00	0.00 +j 0.00
TNB	In	1.00	0.00	21.7	0.5	-0.50	0.01 +j 0.06

PQ Generators

Participation PQ Source	In/Out Service	VD %	Vp.u.	KW	KVAR
G-59-01A	In	-0.80	1.010	7,550.0	3,520.0
G-59-01B	In	-0.80	1.010	7,550.0	3,520.0
G-59-01C	Out	-0.59	1.010	0.0	0.0

Bus Name	In/Out Service	Design Volts	LF Volts	Angle Degree	PU Volts	%VD
BUS-0066	In	3.300	3.339	-0.77	1.01	-1.19
BUS-0067	In	3.300	3.346	-0.79	1.01	-1.41
BUS-0068	In	3.300	3.376	-0.08	1.02	-2.30
BUS-0069	In	11.000	11.032	-0.03	1.00	-0.29
BUS-0070	In	11.000	11.055	0.00	1.00	-0.50
BUS-0071	In	11.000	11.055	0.00	1.00	-0.50
BUS-0072	In	3.300	3.376	-0.08	1.02	-2.30
BUS-0073	In	3.300	3.362	0.00	1.02	-1.89
BUS-0074	In	11.000	11.043	-0.02	1.00	-0.39
BUS-0075	In	11.000	11.042	-0.02	1.00	-0.38
BUS-0076	In	11.000	11.043	-0.02	1.00	-0.39
BUS-0077	In	11.000	11.042	-0.02	1.00	-0.38
BUS-0078	In	3.300	3.376	-0.08	1.02	-2.30
BUS-0079	In	11.000	11.031	-0.03	1.00	-0.29
BUS-0080	In	11.000	11.031	-0.03	1.00	-0.29
BUS-0081	In	11.000	11.039	-0.02	1.00	-0.36
BUS-0082	In	11.000	11.039	-0.02	1.00	-0.35
BUS-0083	In	3.300	3.340	-0.83	1.01	-1.21
BUS-0084	In	3.300	3.340	-0.83	1.01	-1.21
BUS-0085	In	3.300	3.313	-0.67	1.00	-0.41
BUS-0086	In	3.300	3.333	-0.78	1.01	-0.99
BUS-0087	In	3.300	3.321	-0.75	1.01	-0.62
BUS-0088	In	11.000	11.031	-0.03	1.00	-0.28
BUS-0089	In	11.000	11.040	-0.02	1.00	-0.36
BUS-0090	In	3.300	3.340	-0.83	1.01	-1.21
BUS-0098	In	415	0	0.00	0.00	100.00

Bus Name	In/Out Service	Design Volts	LF Volts	Angle Degree	PU Volts	%VD
SB103N2	In	415	417	-2.55	1.01	-0.58
SB103N3	In	415	417	-1.06	1.01	-0.51
SB103N4	In	415	413	-1.78	0.99	0.54
SB104C1L	In	11.000	11.043	-0.02	1.00	-0.39
SB104C1R	In	11.000	11.042	-0.02	1.00	-0.38
SB104E21	In	415	417	-1.09	1.01	-0.56
SB104N1	In	415	414	-1.55	1.00	0.35
SB104N2	In	415	414	-1.55	1.00	0.36
SB104N3	In	415	418	-0.91	1.01	-0.83
SB104N4	In	415	417	-1.08	1.01	-0.59
SB106E21	In	415	409	-0.78	0.99	1.45
SB106N1	In	415	409	-0.70	0.99	1.33
SB106N2	In	415	409	-0.77	0.99	1.44
SB132A1L	In	132.000	132.660	0.00	1.00	-0.50
SB132A1R	In	132.000	132.660	0.00	1.00	-0.50
SB132C1L	In	11.000	11.055	0.00	1.00	-0.50
SB132C1R	In	11.000	11.055	0.00	1.00	-0.50
SB132E21	In	415	424	-1.81	1.02	-2.11
SB132N1	In	415	426	-1.44	1.03	-2.68
SB132N2	In	415	424	-1.79	1.02	-2.16
SB201C1L	In	11.000	11.065	0.04	1.01	-0.59
SB201C1R	In	11.000	11.065	0.04	1.01	-0.59
SB201E21L	In	415	419	-0.91	1.01	-0.85
SB201E21R	In	415	413	-1.67	1.00	0.38
SB201E31R0	In	415	413	-1.67	1.00	0.37

From Bus To Bus	Component Name	In/Out Service	%VD	kW Loss	kvar Loss	kVA Loss	LF Amps Rating %	PF
SB102C1L BUS-0056	CBL-0029	In	0.00	515.6 0.0	283.3 0.0	588.3 0.0	30.8 6.4	0.88
SB102C1R BUS-0055	CBL-0028	In	0.02	1,820.1 0.3	1,108.3 0.2	2,131.0 0.3	111.4 23.2	0.85
SB102C1R BUS-0057	CBL-0030	In	0.00	826.0 0.0	472.9 0.0	951.8 0.0	49.8 10.4	0.87
SB102D1L BUS-0058	CBL-0031	In	0.28	193.3 0.7	137.0 0.1	237.0 0.7	41.2 21.7	0.82
SB102D1L BUS-0059	CBL-0032	In	0.20	280.7 0.7	232.3 0.3	364.4 0.8	63.3 19.2	0.77
SB102D1L BUS-0060	CBL-0033	In	0.20	493.6 1.0	224.8 0.4	542.3 1.1	94.3 28.6	0.91
SB102D1L BUS-0061	CBL-0034	In	0.40	1,173.2 5.1	664.0 2.0	1,348.1 5.5	234.3 35.5	0.87
SB102D1L BUS-0062	CBL-0035	In	0.18	1,165.3 2.0	531.2 1.2	1,280.7 2.3	222.6 26.5	0.91
SB102D1R BUS-0063	CBL-0036	In	0.24	757.6 2.0	488.9 0.8	901.6 2.2	155.6 23.6	0.84
SB102D1R BUS-0064	CBL-0037	In	0.21	165.5 0.4	102.4 0.1	194.6 0.4	33.6 17.7	0.85
SB102D1R BUS-0065	CBL-0038	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB102D1R BUS-0066	CBL-0039	In	0.22	894.5 2.0	482.6 0.8	1,016.4 2.2	175.4 26.6	0.88

From Bus To Bus	Component Name	In/Out Service	%VD	kW Loss	kvar Loss	kVA Loss	LF Amps Rating %	PF
SB132C1L BUS-0071	CBL-0044	In	0.00	465.7 0.0	292.9 0.0	550.2 0.0	28.7 6.0	0.85
SB132C1L SB101C1L	CBL-0003	In	0.01	127.2 0.0	76.7 0.0	148.5 0.0	7.8 1.4	0.86
SB132C1L SB102C1L	CBL-0005	In	0.20	3,835.9 6.2	2,190.0 6.5	4,417.1 9.0	230.7 20.8	0.87
SB132C1L SB103C1L	CBL-0007	In	0.21	2,322.0 4.1	1,508.5 4.3	2,769.0 6.0	144.6 26.1	0.84
SB132C1L SB104C1L	CBL-0009	In	0.11	756.2 0.7	518.7 0.7	917.0 1.0	47.9 8.6	0.82
SB132C1R BUS-0045	CBL-0018	In	0.02	223.8 0.0	146.5 0.0	267.5 0.0	14.0 2.5	0.84
SB132C1R BUS-0070	CBL-0043	In	0.00	575.6 0.0	363.9 0.0	681.0 0.0	35.6 7.4	0.85
SB132C1R SB101C1R	CBL-0004	In	0.08	807.1 0.5	474.2 0.6	936.1 0.8	48.9 8.8	0.86
SB132C1R SB102C1R	CBL-0006	In	0.14	2,649.2 3.0	1,584.4 3.2	3,086.8 4.4	161.2 14.5	0.86
SB132C1R SB103C1R	CBL-0008	In	0.14	1,482.9 1.7	1,001.7 1.8	1,789.5 2.5	93.5 16.8	0.83
SB132C1R SB104C1R	CBL-0010	In	0.11	807.8 0.8	549.0 0.8	976.7 1.1	51.0 9.2	0.83
SB132E21 SB103E11	CBL-0073	In	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00

From Bus To Bus	Component Name	%VD	kW Loss	kvar Loss	kVA Loss	LF Amps Rating %	PF
SB132A1L SB132A1R	PI-0001	0.00	10.8 0.0	0.2 0.0	10.8 0.0	0.0 0.0	1.00
SB132C1L SB132C1R	PI-0002	0.00	-579.3 0.0	-300.5 0.0	652.6 0.0	34.1 0.0	0.89
SB201C1L SB201C1R	PI-0003	0.00	113.7 0.0	79.3 0.0	138.6 0.0	7.2 0.0	0.82
SB201E21L SB201E21R	PI-0004	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB101C1L SB101C1R	PI-0005	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB101N1 SB101N2	PI-0006	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB101D1L SB101D1R	PI-0007	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB102C1L SB102C1R	PI-0008	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB102N1 SB102N2	PI-0009	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB102D1L SB102D1R	PI-0010	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103C1L SB103C1R	PI-0011	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103N3 SB103N4	PI-0012	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00
SB103D1L SB103D1R	PI-0013	0.00	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.00

APPENDIX IV– Load Flow Analysis Flowchart

APPENDIX 4 – Load Flow Analysis Flowchart

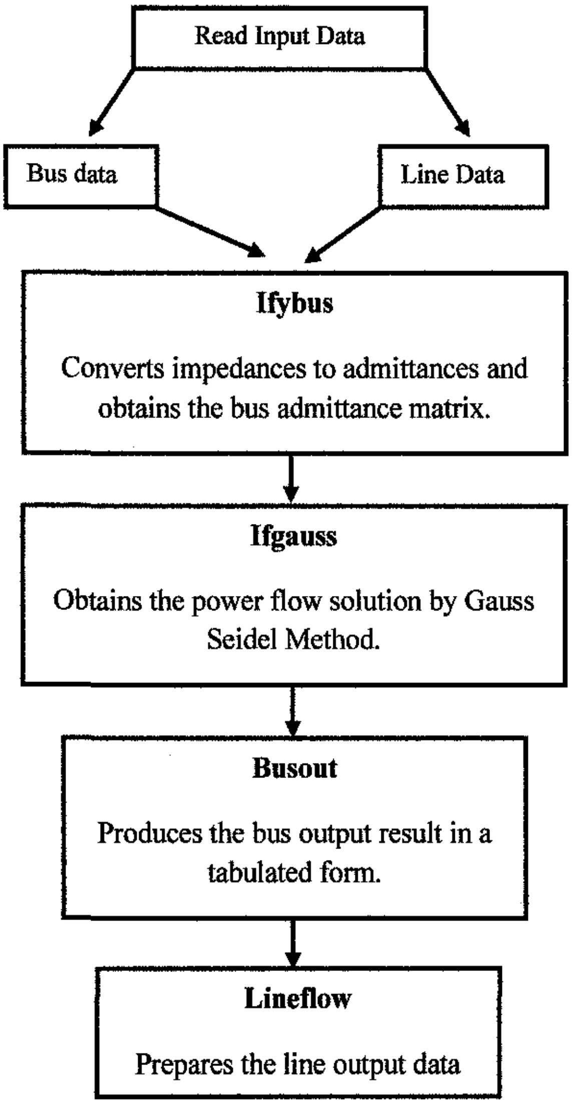

Figure 11: Load Flow Analysis Flowchart

APPENDIX 4 – Load Flow Analysis Flowchart

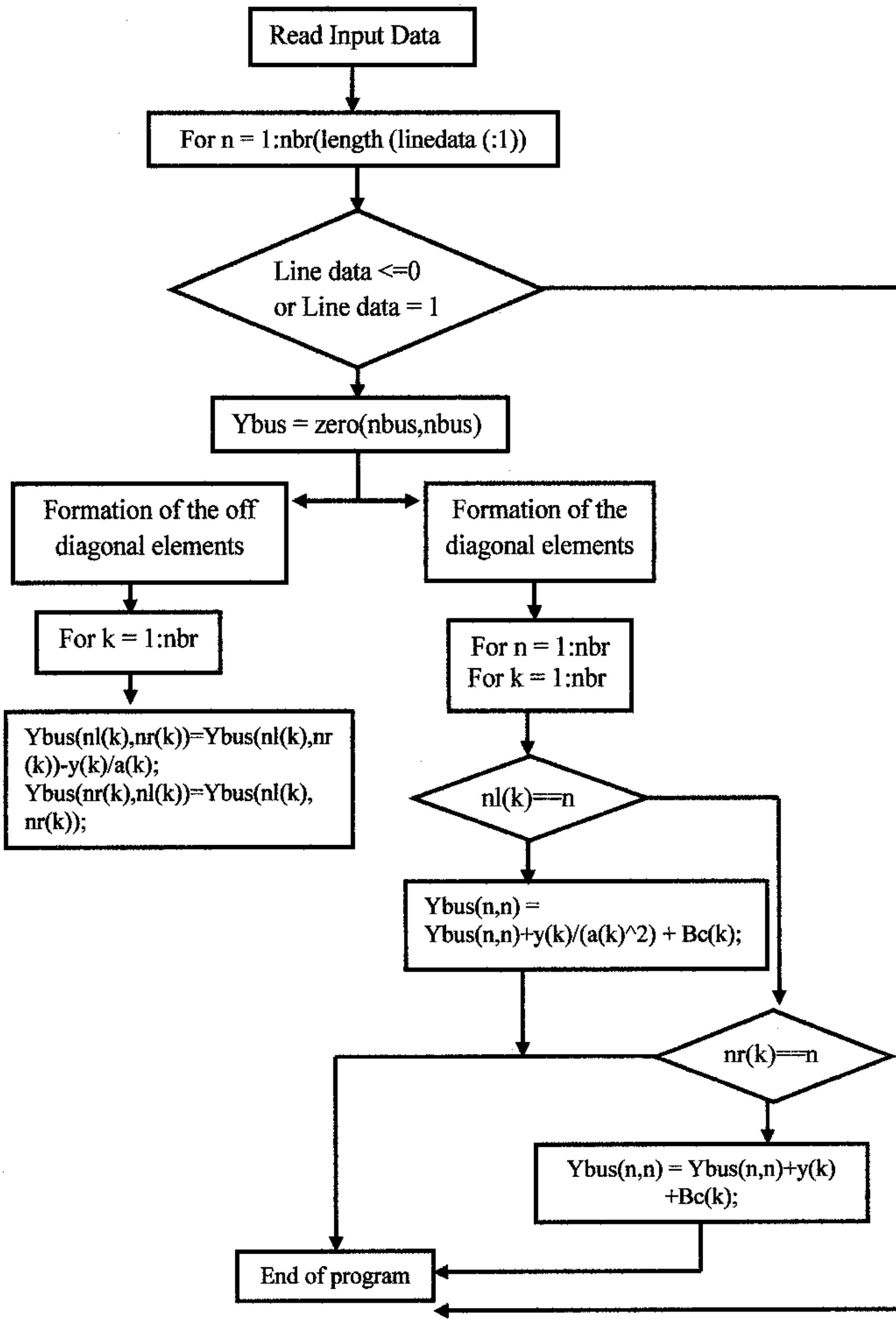

Figure 12: Ifybus Program Code Flowchart

APPENDIX 4 – Load Flow Analysis Flowchart

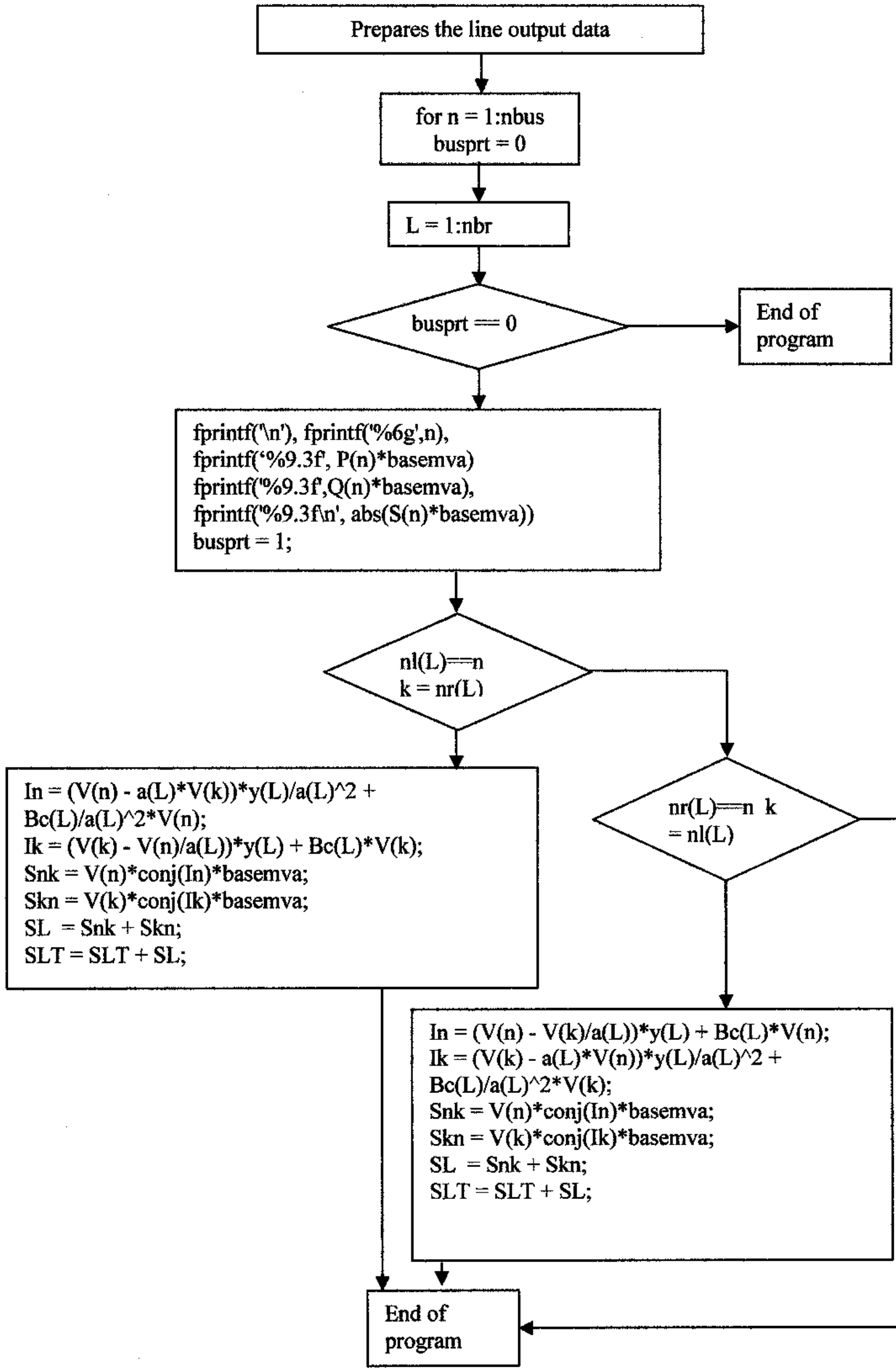

Figure 13: Lineflow Program Code Flowchart

APPENDIX V– Tables and Figures for Impedance Calculation

Table 1

Typical Reactance Values for Induction and Synchronous Machines, in Per-Unit of Machine kVA Ratings*

	X''_d	X'_d
Turbine generators†		
2 poles	0.09	0.15
4 poles	0.15	0.23
Salient-pole generators with damper windings†		
12 poles or less	0.16	0.33
14 poles or more	0.21	0.33
Synchronous motors		
6 poles	0.15	0.23
8—14 poles	0.20	0.30
16 poles or more	0.28	0.40
Synchronous condensers†	0.24	0.37
Synchronous converters†		
600 V direct current	0.20	—
250 V direct current	0.33	—
Individual induction motors, usually above 600 V	0.17	—
Groups of motors, each less than 50 hp, usually 600 V and below‡	0.25	—

NOTE: Approximate synchronous motor kVA bases can be found from motor horsepower ratings as follows:

0.8 power factor motor — kVA base = hp rating

1.0 power factor motor — kVA base = 0.8 × hp rating

*Use manufacturer's specified values if available.

†X'_d not normally used in short-circuit calculations.

‡The value of X''_d for groups of motors has been increased slightly to compensate for the very rapid short-circuit current decrement in these small motors. A lower value of X''_d will normally be appropriate for groups of large motors.

Table 2

Representative Conductor Spacings for Overhead Lines

Nominal System Voltage (volts)	Equivalent Delta Spacing (inches)
120	12
240	12
480	18
600	18
2400	30
4160	30
6900	36
13 800	42
23 000	48
34 500	54
69 000	96
115 000	204

NOTE to Table 19:

When conductors are not arranged in a delta, the following formula may be used to determine the equivalent delta:

$$d = \sqrt[3]{A \times B \times C}$$

When the conductors are located in one plane and the outside conductors are equally spaced from the middle conductor, the equivalent is 1.26 times the distance between the middle conductor and an outside conductor. For example,

$$\text{equivalent delta spacing} = \sqrt[3]{A \times A \times 2A} = 1.26\,A$$

Table 3

Constants of Copper Conductors for 1 ft Symmetrical Spacing*

Size of Conductor (cmil)	(AWG No.)	Resistance R at 50°C, 60 Hz (Ω/conductor/1000 ft)	Reactance X_A at 1 ft Spacing, 60 Hz (Ω/conductor/1000 ft)
1 000 000		0.0130	0.0758
900 000		0.0142	0.0769
800 000		0.0159	0.0782
750 000		0.0168	0.0790
700 000		0.0179	0.0800
600 000		0.0206	0.0818
500 000		0.0246	0.0839
450 000		0.0273	0.0854
400 000		0.0307	0.0867
350 000		0.0348	0.0883
300 000		0.0407	0.0902
250 000		0.0487	0.0922
211 600	4/0	0.0574	0.0953
167 800	3/0	0.0724	0.0981
133 100	2/0	0.0911	0.101
105 600	1/0	0.115	0.103
83 690	1	0.145	0.106
66 370	2	0.181	0.108
52 630	3	0.227	0.111
41 740	4	0.288	0.113
33 100	5	0.362	0.116
26 250	6	0.453	0.121
20 800	7	0.570	0.123
16 510	8	0.720	0.126

Table 4

Constants of Aluminum Cable, Steel Reinforced, for 1 ft Symmetrical Spacing*

Size of Conductor (cmil)	(AWG No.)	Resistance R at 50°C, 60 Hz (Ω/conductor/1000 ft)	Reactance X_A at 1 ft Spacing, 60 Hz (Ω/conductor/1000 ft)
1 590 000		0.0129	0.0679
1 431 000		0.0144	0.0692
1 272 000		0.0161	0.0704
1 192 500		0.0171	0.0712
1 113 000		0.0183	0.0719
954 000		0.0213	0.0738
795 000		0.0243	0.0744
715 500		0.0273	0.0756
636 000		0.0307	0.0768
556 500		0.0352	0.0786
477 000		0.0371	0.0802
397 500		0.0445	0.0824
336 400		0.0526	0.0843
266 800		0.0662	0.1145
	4/0	0.0835	0.1099
	3/0	0.1052	0.1175
	2/0	0.1330	0.1212
	1/0	0.1674	0.1242
	1	0.2120	0.1259
	2	0.2670	0.1215
	3	0.3370	0.1251
	4	0.4240	0.1240
	5	0.5340	0.1269
	6	0.6740	0.1273

NOTE: For a three-phase circuit the total impedance, line to neutral, is

$$Z = R + j(X_A + X_B)$$

*Use spacing factors of Tables 5 and 6 for other spacings.

APPENDIX VI– Load Flow Result Using PSAT

OWER FLOW REPORT

S A T 2.1.5

uthor: Federico Milano, (c) 2002-2009
-mail: Federico.Milano@uclm.es
ebsite: http://www.uclm.es/area/gsee/Web/Federico

ile: C:\Users\Nurul Farhana\Documents\MATLAB\psat\FYP\fyp.mdl
ate: 03-May-2010 16:50:17

ETWORK STATISTICS

uses:	12
ines:	6
ransformers:	7
enerators:	4
oads:	6

OLUTION STATISTICS

umber of Iterations:	21
aximum P mismatch [p.u.]	0.13824
aximum Q mismatch [p.u.]	0
ower rate [MVA]	100

OWER FLOW RESULTS

us	V [p.u.]	phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
us 1	1.06	0	-0.0774	0.49443	0	0
us 10	0.43205	-0.30784	0	0	0.00597	0.00448
us 11	0.44095	-0.28361	0	0	0.00081	0.00061
us 12	0.43966	-0.28579	0	0	0.0008	0.0006
us 2	1	0.26915	0.13824	-0.24404	0	0
us 3	1.01	2.5441	0.03725	0.07572	0	0
us 4	1.01	2.544	0.03725	0.07676	0	0
us 5	0.98701	2.5342	0	0	0.00163	0.00122
us 6	0.96858	2.5264	0	0	0.00288	0.00216
us 7	0.44597	-0.26874	0	0	0	0
us 8	0.44467	-0.27091	0	0	0	0
us 9	0.43362	-0.30483	0	0	0.00588	0.00441

aximum reactive power limit violation at bus <Bus 1> [Qg_max = 0.31779]
inimum voltage limit violation at bus <Bus 10> [V_min = 0.8]
inimum voltage limit violation at bus <Bus 11> [V_min = 0.8]
inimum voltage limit violation at bus <Bus 12> [V_min = 0.8]
inimum reactive power limit violation at bus <Bus 2> [Qg_min = -0.0064]
aximum reactive power limit violation at bus <Bus 3> [Qg_max = 0]
aximum reactive power limit violation at bus <Bus 4> [Qg_max = 0]
inimum voltage limit violation at bus <Bus 7> [V_min = 0.8]
inimum voltage limit violation at bus <Bus 8> [V_min = 0.8]
inimum voltage limit violation at bus <Bus 9> [V_min = 0.8]

TATE VARIABLES

elta_Syn_1	2.5447
mega_Syn_1	1
elta_Syn_2	2.5446
mega_Syn_2	1
m_Exc_1	1.01
r1_Exc_1	1.035
r2_Exc_1	-101.7228
f_Exc_1	1.0172
m_Exc_2	1.01
r1_Exc_2	1.035
r2_Exc_2	-101.7146
f_Exc_2	1.0172

THER ALGEBRAIC VARIABLES

f_Syn_1	1.0172
m_Syn_1	0.03746
_Syn_1	0.03725
_Syn_1	0.07572
f_Syn_2	1.0172
m_Syn_2	0.03747
_Syn_2	0.03725
_Syn_2	0.07676
ref_Exc_1	1.0152
ref_Exc_2	1.0152

INE FLOWS

rom Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
us 3	Bus 2	1	0.03494	0.07581	0.00011	0.15076
us 4	Bus 2	2	0.03494	0.07581	0.00011	0.15076
us 7	Bus 8	3	4e-005	5e-005	0	-1e-005
us 2	Bus 7	4	0.00674	0.01813	1e-005	0.01271
us 2	Bus 8	5	0.00674	0.01817	1e-005	0.01277
us 3	Bus 4	6	0.00065	-0.00136	0	-0.00271
us 7	Bus 11	7	0.00081	0.00062	0	2e-005
us 8	Bus 12	8	0.0008	0.00062	0	2e-005
us 1	Bus 2	9	-0.0774	0.49443	0.11702	0.0642
us 3	Bus 5	10	0.00166	0.00127	3e-005	4e-005
us 4	Bus 6	11	0.00296	0.00231	8e-005	0.00015
us 7	Bus 9	12	0.00588	0.00475	0	0.00034
us 8	Bus 10	13	0.00597	0.00483	0	0.00035

INE FLOWS

rom Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
us 2	Bus 3	1	-0.03483	0.07495	0.00011	0.15076

us 2	Bus 4	2	-0.03483	0.07495	0.00011	0.15076
us 8	Bus 7	3	-4e-005	-5e-005	0	-1e-005
us 7	Bus 2	4	-0.00673	-0.00542	1e-005	0.01271
us 8	Bus 2	5	-0.00673	-0.0054	1e-005	0.01277
us 4	Bus 3	6	-0.00065	-0.00136	0	-0.00271
us 11	Bus 7	7	-0.00081	-0.00061	0	2e-005
us 12	Bus 8	8	-0.0008	-0.0006	0	2e-005
us 2	Bus 1	9	0.19442	-0.43024	0.11702	0.0642
us 5	Bus 3	10	-0.00163	-0.00122	3e-005	4e-005
us 6	Bus 4	11	-0.00288	-0.00216	8e-005	0.00015
us 9	Bus 7	12	-0.00588	-0.00441	0	0.00034
us 10	Bus 8	13	-0.00597	-0.00448	0	0.00035

LOBAL SUMMARY REPORT

ЭTAL GENERATION

EAL POWER [p.u.] 0.13534
EACTIVE POWER [p.u.] 0.40287

ЭTAL LOAD

EAL POWER [p.u.] 0.01797
EACTIVE POWER [p.u.] 0.01348

ЭTAL LOSSES

EAL POWER [p.u.] 0.11737
EACTIVE POWER [p.u.] 0.38939

IMIT VIOLATION STATISTICS
OF VOLTAGE LIMIT VIOLATIONS: 6
OF REACTIVE POWER LIMIT VIOLATIONS: 4
_L CURRENT FLOWS WITHIN LIMITS.
_L REAL POWER FLOWS WITHIN LIMITS.
_L APPARENT POWER FLOWS WITHIN LIMITS.